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R. W. Hansen, J. M. Harper, M. L. Stone, G. M. Ward and R. A. Kidd

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To develop a basis for better manure harvesting management practices a combined field and laboratory study was conducted.

The effect of management practices on manure qualities and runoff pollution potential were compared on three feedlot pens with fully surfaced, partially surfaced and unsurfaced conditions.

Average N, P and K elements were present in a ratio of approximately 4:1:2 providing 46 lbs N, 11 lbs P and 27 lbs K per ton of dry manure.

For recycling purposes ash is an important fraction of manure and can be reduced by use of hard surfaced pens. Ash content averaged 36.2%. Fiber and lignin in manure are directly related to the fiber content of the ration.

The effect of decomposition of the manure was greatest on its viscosity and squeezability. Bulk density and particle size remained the same.

Surfaced feedlot areas have a larger percentage of precipitation in runoff with higher concentrations of pollutants. Increased animal densities on surfaced pens will offset the difference with non-surfaced pens and can result in a lower per-animal pollution potential from runoff.

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MANURE HARVESTING PRACTICES: EFFECTS ON WASTE CHARACTERISTICS AND RUNOFF

By

Ralph W. Hansen
Judson M. Harper
Marvin L. Stone
Gerald M. Ward
Ricky A. Kidd
Colorado State University
Fort Collins, Colorado 80523

Grant No. R-803378

Project Officer

S. C. Yin
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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ABSTRACT

Decomposition of manure occurs through biological action and spontaneous chemical reactions. These processes are affected by microclimates surrounding the manure, the chemical composition of the manure and the microbiological populations existing in the manure. Initial chemical and biological compositions of manure are a function of the animal's feed, age and other factors. For a given manure the microclimate then controls decomposition.

To develop a basis for better manure harvesting management practices a combined field and laboratory study was conducted. The field studies were located on a commercial beef feedlot in northeastern Colorado.

The effect of management practices on manure qualities and runoff pollution potential was compared on three feedlot pens with fully surfaced, partially surfaced and unsurfaced conditions. Effects of cleaning practices on the surfaced and dirt pens with variable harvesting schedules were compared.

Average N, P and K elements were present in a ratio of approximately 4:1:2 providing 46 lbs N, 11 lbs P and 27 lbs K per ton of dry manure.

For recycling purposes ash is an important fraction of manure and can be reduced by use of hard surfaced pens. Ash content averaged 36.2% with a range from 30.7% to 42.9%. Fiber and lignin in manure are directly related to the fiber content of the ration. Increased fiber and decreased protein in the ration reduces the ash concentration in the manure, although the increase in fiber caused a reduction in nitrogen.

During periods of high temperature more frequent harvesting will minimize ash and fiber concentrations and reduce ammonia losses.

The decomposition rates of manure were studied in the laboratory in a controlled temperature-humidity chamber to incubate the manure at constant temperature and moisture levels. During incubation the chemical and

physical properties were monitored. The effect of the decomposition of the manure was greatest on its viscosity and squeezability. The viscosity of a slurry of manure incubated at 70% moisture content and 120°F doubled in a ten-day period. The manure's squeezability decreased 6% in the same period. In contrast, the bulk density and particle size remained the same.

Hard surfacing and more frequent cleaning schedules will be a departure from more conventional feedpen management methods. In conjunction with the use of new manure harvesting techniques, there will be an effect on feedlot runoff pollution potential. Surfaced feedlot areas have a larger percentage of the precipitation in runoff with a higher concentration of pollutants. Since animal densities can be increased on surfaced pens, the pollution potential on a per animal basis is no more serious than for unsurfaced pens.

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Several research assistants, graduate research assistants and temporary employees helped with the installation of equipment, collection of samples and data, and the analyses of samples in the laboratory.

SECTION I

CONCLUSIONS

Recycling of manure emphasizes the importance of management practices to optimize the recovery of useful components in the manure.

Ash and acid detergent fiber (ADF) are major chemical constituents in manure. The rate of increase of both was found with higher temperatures and moistures. Ammonia nitrogen is lost in warm and wet conditions. The increase in ash is accompanied by a decrease in organic matter.

To minimize losses, shorter manure harvesting periods are suggested during seasons with high temperature, and particularly when accompanied by high moisture conditions, at least monthly manure collection would be recommended.

The viscosity of a manure slurry will increase with time and the squeezability will decrease. Viscosity changes may have a significant effect on manure reuse. Any process that uses slurried manure could develop large increases in viscosity over relatively short periods of storage (10 days), complicating handling and processing.

The primary fertilizer elements, N, P and K, were present in a ratio of approximately 4:1:2 which would provide a generally useful fertilizer. The average quantity per ton of dry manure was 46 lbs N, 11 lbs P and 27 lbs K. An average of 40 lbs Ca per ton dry manure was found. This could be of value on some soils.

The fibrous components of manure are closely related to the crude fiber content of the ration. Feeding operations utilizing high roughage rations will produce manure with constituents suitable for methane gas production.

Surfaced feedlot pens will facilitate frequent harvesting of the manure and reduce maintenance problems. Surfaced areas will, however, have a higher potential for pollution from increased runoff of higher concentration when rainfall occurs. Since animal densities can be increased in surfaced pens, the pollution potential on a per animal basis is no more serious than for unsurfaced pens.

SECTION II

RECOMMENDATIONS

The decomposition of manure is most rapid during periods of high temperature and high moisture. Significant changes in the constituents will occur. If the manure is being utilized for recycling purposes, consideration should be given to more frequent cleaning under these conditions.

A general recommendation can be made, that for most purposes, the harvesting schedule should be no longer than one month during hot, wet weather to minimize the losses. Each installation should be considered individually, however, and the harvesting schedule based on local conditions, value of the manure components, cost of more frequent harvesting and increased return from following these practices.

As characteristics of feedlot wastes vary widely, any use, including land application rates, should be based upon laboratory analysis from individual feedlots. If such is not available, a recommended value for feedlot manure from Colorado feedlots is an N:P:K ratio of 4:1:2 with a dry ton of manure providing 46 lbs N, 11 lbs P and 27 lbs K. While this study did not include any work on the availability of the nutrients, it is assumed the recommendations of other investigators would apply; namely, the first year feedlot manure is applied to the land, apply at twice the rate necessary to meet nitrogen fertilizer recommendations. Apply at the rate needed to meet nitrogen requirements in subsequent years.

The current value of manure as a resource for further processing or recycling generally does not warrant very sophisticated quality analysis and control; however, as it becomes more valuable, there will be opportunity to fit certain utilization processes to individual feedlot operations for maximum use. For example, high roughage feeding operations will provide a manure with a carbon constituent that might best be used for pyrolysis processes which can utilize this characteristic.

Surfaced feedpens will be essential for harvesting manure for most purposes. Ash content is normally high and is seriously increased by contamination from dirt in unsurfaced pens.

To offset the additional cost for surfacing, the density of animals should be increased. The optimum density for localized conditions is unknown; however, experience with full confinement systems would indicate that densities around 50 sq ft per animal should be adequate for surfaced feedpens and possibly could be reduced below this figure.

SECTION III

INTRODUCTION

BACKGROUND

The recycling of beef feces is being done for various purposes at several installations throughout the country. Recycled manure can be processed for feed material, used as a raw material for the production of gas, oil, methane, synthesis gas, protein, or pyrolyzed to reclaim useable constituents.

In harvesting manure for these purposes, little is known about the effects of environment and management practices on the manure's physical, biological and nutritional properties. Several things may happen to manure after it is deposited on the feedlot surface.

Frecks and Gilbertson[1] have shown the effects of ration on physical properties of manure. Their work does not contain any information on the effects of aging or changes in the environment on the manure. Shaw and Boyd[2] have characterized viscosity of manure but not with respect to age. They found slurries from different locations acted as a pseudoplastic. This study characterized viscosity as a function of moisture content and bedding type. Sobel[3] has characterized animal wastes as to density, particle size, settleable and dissolved solids and settling rate. These studies provide the basic techniques for conducting analysis on manure.

Manure from feedlots represents a useful resource that when properly processed can be utilized rather than wasted. The components of manure represent materials useful as reclaimable feed or the base material for the production of energy and other resources.

The increased interest in utilizing manure as a fertilizer, fuel and feed source has focused attention upon manure qualities. The reuse of manure emphasizes the need for proper management of the manure to retain its utilizable components. Many components of manure can be lost or reduced through decomposition on the feedlot surface and during storage. McCalla[4] found losses of up to 90% of the nitrogen in manure while the manure was left on the feedlot surface. Data are needed that can be used as a basis to determine the best manure management harvesting practices. Component losses may then be reduced to a minimum in harvesting practices used to produce optimal manure utilization techniques.

Decomposition of manure occurs through enzymatic biological action and spontaneous chemical reactions. These processes are affected by the microclimate surrounding the manure, the chemical composition of the manure and the microbiological populations existing in the manure. The initial chemical and biological composition of manure is a function of the animal's feed, age and other factors. For a given manure, the microclimate then controls decomposition.

UTILIZATION OF MANURE

Manure has long been used as a fertilizer. The recent fertilizer shortages have emphasized the necessity of preserving the nutritional qualities of manure for plant production. Graber[5] gives the fertilizer ingredients of typical beef feedlot manure from one ton at 40% moisture as 10 lbs N, 5 lbs P_2O_5 and 10 lbs K_2O.

Manure as a Fuel

Halligan and Sweazy[6] report the B.T.U. rating of beef feedlot manure as high as 6,500 B.T.U. per pound or 13×10^6 B.T.U. per ton (D.M.B.). There are three means of utilizing manure as a fuel: direct combustion, substrate for methane production, and production of synthetic fuel.

Direct combustion is possible only when the moisture content of the manure is sufficiently low (<25%) to sustain combustion. "Trash" type furnaces and air pollution equipment are required. The ash has value as a fertilizer since only nitrogen and humus are lost in the combustion.

Manure used as a substrate for methane generation must be diluted to 5% solids and held at a temperature of 110-114°F for 15-30 day detentions. A 100-head herd would require 5,000-6,000 ft^3 of fermentation tanks. This system would produce about 4,000 ft^3 of low value (500 B.T.U./ft^3) gas per day. A lagoon is required to handle the sludge since only 50% of the solids would be converted to gas (Fairbank[7]).

Walawender[8] states of the three technologies contemplated for synthetic fuel production, liquefaction, hydrogasification, and pyrolysis for synthesis gas, the latter is generally agreed to be the most promising.

Pyrolysis requires high temperature heating and high pressure in the absence of air to produce a variety of products, including CO, CO_2, CH_4 and H_2.

Manure as a Livestock Feed

Manure has a relatively large potential value as livestock feed and has spawned a variety of handling and processing techniques.

Use of manure as feed requires satisfaction of several subcriteria:

1. Manure contains residues of potentially harmful substances (heavy metals, antibiotics and pesticides) and residues of indigestible materials (lignin and mineral matter, amounting to 20-40% of the total) which would rapidly accumulate in recycling to prevent its use as a feed. This accumulation cycle must be broken. There are three ways:
   A. Dispersion to animals other than those producing manure;
   B. Dilution through using only a fraction of the manure as feed and disposal of the balance, and
   C. Extraction and disposal of these residues as a continuous "blow down" feature of the process.
2. Manure can contain pathogens, and safety against infection can only be assured through continuous thermal and/or chemical processing.
3. The feed products must be palatable to livestock and possess good "shelf life" in storage and in the feed bunk.
4. Since on-farm livestock will typically not consume all the manure-derived feeds produced, it is necessary that at least a fraction be in the form of readily transportable and marketable products if all the manure is to be utilized.

There are four basic technologies:

1. Whole manure drying;
2. The wastelage system;
3. Fractionation with partial recovery, and
4. Fractionation with full recovery.

Whole Manure Drying

In the arid areas of the world, air-dried manure has been directly used in feed rations. Since there is no pathogen control, this is not a feasible technology.

Dried poultry waste (DPW) is dried with a rotary drier and used as a feed. Particle temperatures in drying do not typically attain pasteurization levels. The very dry state of the feed inhibits biological activity and no cases of infection have been reported to date.

The Wastelage System

The wastelage system (Anthony[9]) consists of blending 40% wet (70-80% moisture) manure with dry standard feed ingredients and then ensiling the mixture for over 10 days detention. Preferably fermentation takes place in a top loading, bottom unloading airtight silo to insure uniform fermentation. The pH drops to near 4.0. This acidic state, while not theoretically sufficient to insure destruction of all possible pathogens, certainly destroys most and inhibits biological activity throughout the feed cycle. Excellent feed results with cattle have been obtained using wastelage. This system utilizes only about 25% of the manure produced and does not present an opportunity for utilization for all the manure produced.

Fractionation with Partial Recovery

In these systems manure is washed and settled and one or the other fraction is refed.

At Illinois University (Harmon *et al.*[10]), swine manure is treated in an oxidation ditch and the protein-containing water is fed to swine as drinking water. While excellent feed results have been obtained, it is hard to visualize biological control in this wet, basic medium. Research is providing further evaluation of this technique.

Corral Industries of Phoenix, Arizona (Gross[11]) manufactures a system for screening dilute solutions of manure and then pressing and chemically sterilizing the fibrous fraction for cattle feed as a roughage replacer in the ration. The liquid fraction is then pumped to lagoons for eventual disposal on fields as a fertilizer.

Ceres Ecology Corporation (Seckler[12]) manufactures a similar system -- consisting of the C1 line of Figure 1 -- for use in small to medium size livestock operations. The value of the roughage feed produced in these systems is about equal to that of low to medium grade corn silage.

Fractionation with Full Recovery

Feed Cycling Company of Blyth, California (Senior[13]) has developed a system for extracting sand from beef feedlot manure and ending with a feed product (82% of the input) in a dry pelleted form containing about 20% crude protein, 39% cellulose and lignin, and 14% ash. The system entails a brine discharge into salt beds.

Ceres Ecology Corporation, in cooperation with W. Brady Anthony and the Auburn Research Foundation, has developed a system which is designed to produce different feeds for ruminant and monogastric animals (Figure 1). "C1" (20-40% of input, D.M.B.) consists of the grain and fiber particles in manure. It is either fermented into a silage product for feeding feedlot cattle or dried, blended and pelleted for range cattle. "C2" (40%) is a dry pelleted product containing 27-30% crude protein, 4% fat, and 25% ash. This product is fermented in the liquid phase to encourage production of "single-cell protein." "C3" (20-40%) is a compost-like material suitable as a soil conditioner of about the same value as manure.

Hamilton Standard Corporation (Turk[14]), in conjunction with the Northern Regional Research Laboratory (U.S.D.A.), has proposed a joint methane-protein system. We do not have sufficient information to evaluate this proposal other than to observe that methane production would increase costs of feed production over systems using other fuel sources and that these high costs of methane generation would not likely be overcome by cost saving and/or added production value in protein production.

General Electric Corporation is also working on a protein fermentation system about which we have little information (Anonymous[15]).

SCOPE

Manure from feedlots represents a useful resource that, when properly processed, can be utilized rather than wasted. The components of manure

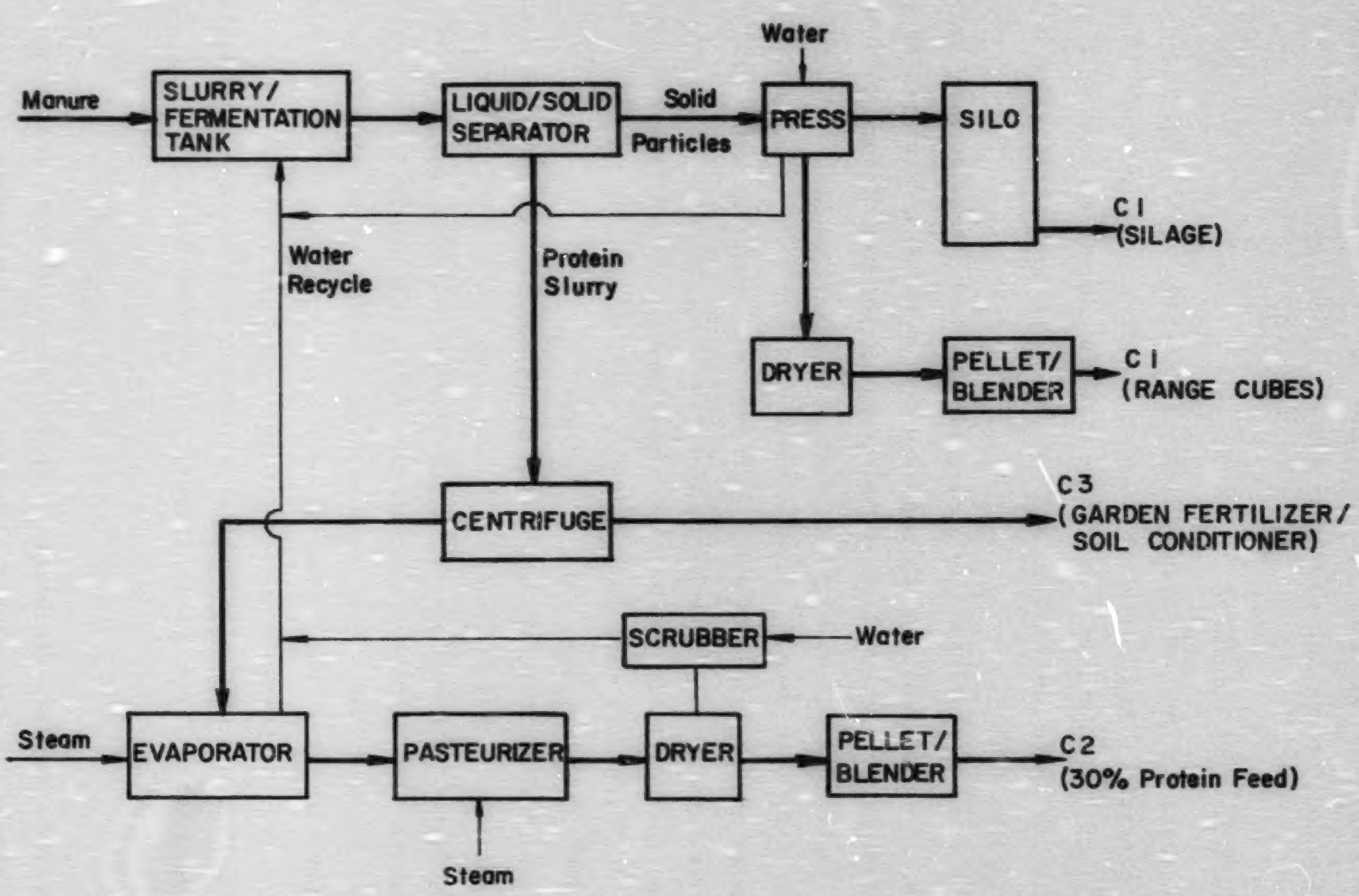
Manure
SLURRY/ FERMENTATION TANK
LIQUID/SOLID SEPARATOR
Solid Particles
Water
PRESS
SILO
C1 (SILAGE)
Water Recycle
Protein Slurry
DRYER
PELLET/ BLENDER
C1 (RANGE CUBES)
CENTRIFUGE
C3 (GARDEN FERTILIZER/ SOIL CONDITIONER)
SCRUBBER
Water
Steam
EVAPORATOR
PASTEURIZER
DRYER
PELLET/ BLENDER
C2 (30% Protein Feed)
Steam

Figure 1. Ceres Ecology Corporation manure fractionation process schematic

represent materials useful as reclaimable feed or the base material for the production of energy and other resources.

This study was undertaken to determine the effects of a controlled environment and constant management factors on the feed value and physical characteristics of manure. Included were the effects of time, temperature, humidity, rainfall, depth, ration and compaction of the feed value, chemical composition, particle size distribution, moisture content, viscosity of slurry and squeezability.

In conjunction with the use of new harvesting techniques, the effects on runoff pollution and odor potential of the feedlots were also studied to determine the effects of hard surfacing and more frequent cleaning schedules in comparison with conventional facilities and methods.

OBJECTIVES

The objectives of the project were:

1. To review existing literature on the effects of management on manure quality as related to the utility of manure as fertilizer and the basic digestibility of cattle rations.
2. To determine the effects on quantity and quality of runoff from feedlots operated for manure harvesting as compared to conventional dirt lot operations.
3. To determine the effect of environment and management practices on the nutritional, biological and physical properties of manure.
4. To develop a manure management program to obtain maximum value from harvested manure to maximize the utilizable components.

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SECTION IV

PROJECT FACILITIES

GENERAL

The field work for this project was conducted at The Ceres Land Company, Sterling Feedlot, located in Logan County approximately one mile northeast of Sterling, Colorado.

The physical plant of The Ceres Land Company, Sterling Feedlot, is approximately 106 acres in a basically agricultural area. The feedlot area slopes generally to the northeast towards the west bank of the South Platte River. A drainage plan has been developed for the confinement area consisting of a network of ditches, trenches and retention ponds for the collection and confinement of surface drainage.

The Ceres Ecology Corporation, in conjunction with The Ceres Land Company, has developed a system to recycle manure by processing it for reuse as a feed material. The field research was conducted in cooperation with their facilities.

Feedlot Pens

The Ceres Land Company feedlots were originally used as unsurfaced pens with approximately 10-foot concrete aprons extending back from the feed bunks, located along the front side of the pens. The surface of the pens slopes away from the feed bunks with runoff water carried across into drainage channels.

To facilitate collection and cleaning for recycling, some of the pens have been concrete surfaced over most of the pen area and some pens have been surfaced over approximately one-half the pen depth or approximately 70 feet back from the feed bunks.

Three pens were selected for use in this project. These consisted of an unsurfaced pen of approximately 64,000 ft^2 in area, a partially surfaced pen of 78,000 ft^2 and a fully surfaced pen of 68,250 ft^2 in area.

Manure Removal from Pens

The manure was removed from the unsurfaced and partially surfaced pens by the schedule normally used by the feedlot for cleaning pens. This is generally done when the stock in the pens is removed and before they are refilled. This allows for the accumulation and build up of approximately four months of manure.

The manure from the surfaced pen was used for recycling through the processing plant and followed a frequent cleaning schedule. The maximum time between cleanings was about two weeks with more frequent cleaning generally occurring.

Manure samples were taken from the front, center, and back of each of these pens for analysis.

The runoff quality and quantity studies were made on these pen surfaces plus some additional pens with comparable features but providing additional variations in the manure pack.

LABORATORY INVESTIGATIONS

The simulation study with controlled environment to determine the effect of various factors on the manure was conducted in a controlled environment chamber with programmed temperature and humidity control at the Agricultural Engineering Research Center.

ANALYTICAL SERVICES

The Animal Sciences Department provided laboratory space and equipment to provide analysis for chemical and nutritional properties of manure samples.

Off-campus analytical services were used for some of the more specialized analyses that it was not practical to perform in the Department.

SECTION V

SUMMARY OF PREVIOUS MANURE DECOMPOSITION RESEARCH

Manure is produced by beef cattle at an average rate of 5.7 dry lbs per day per 1000 lbs animal weight (Whetstone et al.[16]). Using the latest U.S.D.A. statistics, this means in the United States beef cattle produce 80 million dry pounds of manure per day (U.S.D.A.[17]). Beef cattle manure averages 15-20% crude protein on a dry basis. Therefore at least 12 million pounds of crude protein are deposited per day on feedlots. On an annual basis the protein left in this manure is three times the protein produced in wheat in the United States (calculated from U.S.D.A. statistics[17]). Manure also has substantial fertilizer value. The nitrogen produced in cattle manure annually is equivalent to one-third of the commercial nitrogen applied in the United States[17].

Bacterial decomposition of manure can cause losses of up to 90% of its nitrogen as it lies on the feedlot (Gilbertson et al.[18]). This substantial loss is important in the efficient utilization of manure as a protein source or as a nitrogen fertilizer. The information now available on decomposition rates of manure consists only of several studies where decomposed manure was analyzed. More extensive information is available on decomposition rates of manure in lagoon treatment facilities. There is a need therefore to quantify bacterial decomposition of manure on feedlots so more effective management techniques can be applied to its harvest and, consequently, the manure resource can be better utilized.

LITERATURE REVIEW

An extensive amount of literature is available in the general category of animal waste management; yet on the specific topic of decomposition of manure in the feedlot, little is available. This literature review is intended to bring together the reports dealing with decomposition of manure and some of the literature on the characteristics of manure.

DECOMPOSITION OF MANURE

Conclusive data on the decomposition of manure during storage was compiled in the 1900's. A. D. Hall[19] reported work from five sources indicating that from 33% to 38% of the total nitrogen in manures was lost during storage in stalls and later in piles. Successful attempts were made in this era to "rot" manure and actually increase nitrogen, phosphorus and potassium concentrations while reducing the weight of manure by 16% to 20% (Aikman[20]). About this same time Shutte[21] recognized that the loss of nitrogen during the "rotting" of barnyard manure was an expensive process, for as much as 76% of the available fertilizer nitrogen was lost, even when leaching was prevented.

During the late 1950's and early 1960's commercial fertilizers had come into extensive use and the interest in manure was primarily in disposal techniques. Work presented on treatment techniques that rely mainly on decomposition can be divided into three categories:

1. Anaerobic liquid manure treatment;
2. Aerobic liquid manure treatment, and
3. Composting of manure in its natural state.

Anaerobic Liquid Manure Treatment

Hart and Turner[22] did one of the earlier basic studies on animal wastes and anaerobic digestion. They found that 30% to 50% of the total solids in poultry manure was lost due to decomposition in a period of slightly over two years. They also found that 31% to 65% of the volatile solids of the same manure was lost in the same period. Agnew and Loehr[23] worked with beef cattle manure and found similar reductions in total solids, 30% to 55% depending on the loading rate. They listed a ten-day detention time, which is much shorter than that reported by Hart and Turner. The discrepancy in decomposition rates is accounted for in the fact that Loehr and Agnew used a high temperature (35°C) compared to the ambient temperature unmixed digestion used by Hart and Turner.

Swine wastes have been treated by anaerobic digestion and considerable literature has been compiled on the technique. In some studies decomposition rates have been presented. Schmid and Lipper[24] found in a laboratory study they could achieve a 33% reduction in total solids in a 20-day period with a 35°C reactor temperature. They also showed the effect of temperature with a duplicate system running at 20°C, which achieved only a 20% reduction in total solids. Willrich[25] compiled data on a field anaerobic digestor where he was able to measure solids accumulation in the system and therefore total solids reduction by bacterial action. His reactor was at ambient temperature during the spring season in Ames, Iowa. The total solids reduction was 28% over a 54-day detention time.

The performances of the four studies mentioned are summarized in Table 1. The results show that the lab studies had much higher efficiencies than field studies. The decomposition rates of the studies with long detention times may not be as important as most of the decomposition appears to occur in the first ten days and the rate decreases from there on.

Table 1. PERFORMANCE OF ANAEROBIC LIQUID MANURE TREATMENT TECHNIQUES

Manure type	Type of study	Temperature	Detention time	Total solids reduction	Total solids reduction rate	Source
Poultry	Field	Ambient, central Calif., all seasons	2 years	30 to 50%	.06%/day	Hart & Turner[22]
Beef cattle	Lab	35°C	10 days	30 to 55%	4.2 %/day	Agnew & Loehr[23]
Swine	Lab	35°C	20 days	33%	1.65%/day	Schmid & Lipper[24]
Swine	Lab	20°C	20 days	20%	1.0 %/day	Schmid & Lipper[24]
Swine	Field	Ambient, spring, Ames, IA	54 days	28%	.51%/day	Willrich[25]

Aerobic Liquid Manure Treatment

Considerable literature is available on the design, operation and treatment efficiencies of aerobic liquid manure treatment systems. The specific techniques used vary in the method of introducing air into the manure slurry but when operating will have similar characteristics. The literature presented in this review report data on the amount of decomposition that occurred with time and are not categorized by techniques of aeration.

Moore *et al.*[26] reported on the operation of a field oxidation ditch. They calculated the reduction in total solids in the lagoon by recording influent concentration and effluent concentration and measuring sediment after draining the lagoon. Hegg and Larson[27] reported a solids balance for the same lagoon three years later in a similar study. The first study achieved more total decomposition, but a lower rate of decomposition. This was possible through a longer mean detention time and indicates that the rate of decomposition was slowing down. The observation that decomposition rate is inversely proportional to detention time can be made on all the data found and is illustrated in Figure 2.

The high decomposition rates may not be due totally to detention time since laboratory studies used the shortest detention times and would be more efficient than their field counterparts.

Table 2 summarizes the studies found reporting a total solids reduction by aerobic treatment of liquid wastes. Two of these studies were made in the laboratory. Bloodgood and Robson[28] have shown the effects of temperature on the rates of decomposition of liquid dairy manure. They found that increasing the temperature increased the rate of solid reduction. They also found that the total nitrogen may be reduced by as much as 50% in a 14-day period, but generally the nitrogen concentration is higher in the residue after fermentation. Vickers and Genetelli[29], also using laboratory equipment, reported high solids reduction in a short time. Their work was with poultry manure and they were concerned with pollution potential, disregarding other nutrients.

Two field studies involving the aerobic treatment of liquid poultry manure and decomposition amounts were reported. Ludington *et al.*[30] reported the characteristics of a pilot scale oxidation ditch. They found a 53% reduction in total solids in the 137-day mean detention time. They also found that 31% of the total nitrogen had been lost in the same period and the

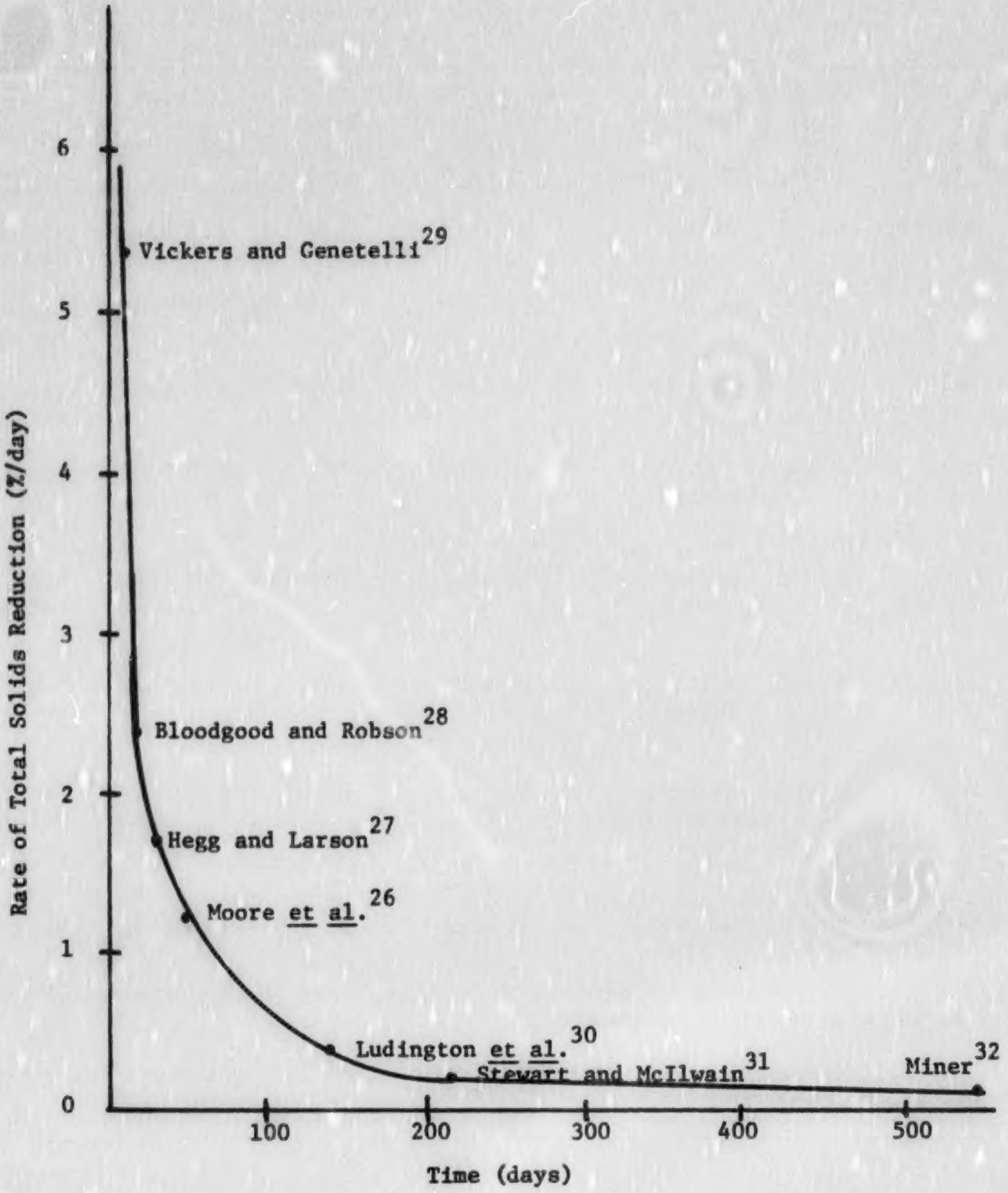

Figure 2. Total solids reduction rate vs. detention time calculated from different sources

Table 2. PERFORMANCE OF AEROBIC LIQUID MANURE TREATMENT TECHNIQUES

Manure type	Type of study	Temperature	Mean detention time	Total solids reduction	Total solids reduction rate	Source
Poultry	Lab	20°C	10 days	53%	5.3 %/day	Vickers & Genetelli[29]
Dairy cattle	Lab	4°C	14 days	17%[a]	1.2 %/day	Bloodgood & Robson[28]
Dairy cattle	Lab	24°C	14 days	34%[a]	2.4 %/day	Bloodgood & Robson[28]
Beef cattle	Field	Ambient, summer, MN	42 days[b]	50%	1.2 %/day	Moore *et al.*[26]
Beef cattle	Field	Ambient, summer, MN	23 days[b]	39%	1.7 %/day	Hegg & Larson[27]
Poultry	Field	Ambient, summer, NY	137 days[b]	53%	0.38%/day	Ludington *et al.*[30]
Poultry	Field	Ambient, poultry house, 20°C	211 days	43%	0.20%/day	Stewart & McIlwain[31]
All	Field	Ambient	1½ years	60 to 70%	0.00%/day	Miner[32]

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[a] Calculated from volatile solids reduction assuming the reported value of 83.5% total volatile solids.

[b] One-half the total operating time was used since the system was batch type with continuous loading.

nitrogen concentration in the ditch had increased during the experiment. A similar study done by Stewart and McIlwain[31] showed a lower decomposition rate for a longer detention time, but a much higher nitrogen loss of 61% to 67%.

The decomposition of organic protein in aerobic liquid manure treatment was summarized (Miner[32]). He suggested, as was observed here, that decomposition rates in lagoons are greatly reduced after 30 days. He also submitted that in one-and-a-half to two years 60% to 70% of the total solids may be decomposed. It is obvious that even if nitrogen concentration in manure increases slightly a 60% to 70% loss of this resource is expensive.

Composting of Manure

Composting is self heating thermophylic aerobic decomposition of an organic substance. A significant amount of attention has been given to the composting of agricultural wastes. The process has the capability of yielding a stable, somewhat odorless end product from agricultural wastes (Willson and Hummel[33]; Wells et al.[34]; Martin et al.[35]; Willson[36]; Howes[37] and Miner[32]).

Four studies were presented from which total solids reduction rate can be calculated. These include Willson[36], Galler and Davey[38], Wells et al.[34] and Toth and Gold[39]. These results are shown in Table 3. The reduction rates are relatively high. This may be due to the high temperatures (120 to 160°F) encountered in composting (Willson[36]; Galler and Davey[38]; Martin et al.[35]; Wells et al.[34]; Toth and Gold[39] and Miner[32]).

Several other observations have been made with respect to decomposition during composting. Volume reductions of 50% have been reported in 30- to 90-day periods (Willson[36] and Martin et al.[35]). Some researchers have reported the nitrogen content was slightly enhanced while others report nitrogen losses (Galler and Davey[38] and Wells et al.[34]). Willson and Hummel[33] reported increases of nitrate levels in composted dairy manure. Changes in pH have also been reported and generally have been found to decrease slightly initially and thereafter increase from pH 6 to pH 8.5 in approximately three days (Martin et al.[35] and Galler and Davey[38]).

Table 3. PERFORMANCE OF MANURE COMPOSTING

Manure type	Detention time	Total solids reduction	Total solids reduction rate	Source
Dairy cattle	33 days[a]	55%	1.67%/day	Willson[36]
Poultry and sawdust	4 days[a]	20%[a]	5.0 %/day	Galler & Davey[38]
General	48-84 days	32-48%[b]	0.50%/day	Toth & Gold[39]
Beef cattle	10 days	20%	2.0 %/day	Wells *et al.*[34]

[a] Average of values given.

[b] On a basis of 80% organic matter in manure.

DECOMPOSITION OF MANURE IN THE FEEDLOT

Some studies have been performed that relate directly to decomposition of whole undiluted manure in storages and on the feedlot surfaces. The element common to all these studies is that the manure was analyzed because it might be later utilized as a plant or animal food. For this reason, nitrogen was analyzed in some form or another in every study and will be reviewed here as an indicator of decomposition.

Waksman[40], in his book on humus, summarized work by Egorov and by Konig indicating decomposed horse manure had a higher protein concentration than the fresh manure. This was attributed to microbial syntheses of protein using non-protein nitrogen as a source. These statements should be viewed in context since the total quantity of nitrogen was found to decrease. Also present was a table indicating the effect of moisture content on the loss of solids during decomposition. The results indicated that increasing the moisture content from 30% to 50% increased the decomposition rate, but any further moisture increase had little effect.

Percent of Dry Material Lost as a Result
of Decomposition of Horse Manure

Percent moisture	30	50	70
Percent reduction in dry matter	38.5	48.2	47.8

McCalla et al.[41] and Gilbertson et al.[18] reported laboratory and field studies that deal with decomposition of beef cattle manure in the feedlot. They found, in laboratory studies, up to 90% of the nitrogen in the manure was lost in three weeks. This may have occurred because urine was added to the manure daily and was volatilized as ammonia. The ammonia concentration was found to be high in the manure and the pH was also high (McCalla et al.[41]). In four months of decomposition in the laboratory 50% of the volatile solids of the manure was lost.

Results found in field studies were similar to the lab results by McCalla et al.[41] and Gilbertson et al.[18]. Twenty-five to 75% of the nitrogen deposited on the feedlot was lost. The nitrogen removed was 10% to 25% ammonia. Nitrates made up an insignificant fraction (Gilbertson et al.[18]).

A laboratory study done by Chang and Johanson[42] has shown that substantial solids are lost during decomposition of dairy wastes. Over a ten-week period 25% to 30% of the total solids was lost. Total nitrogen was also monitored and was found to be lost at about the same percentages as solids. This resulted in no change in the concentration of nitrogen in the manure. Their data also suggested that little change in fixed solids occurred over the period, though variation was high.

Some studies have been done on the decomposition of poultry manure (Flegal et al.[43] and Gilbertson et al.[18]). Though there are basic differences between poultry wastes and beef wastes, the decomposition that occurs produces similar products in both types of wastes. One-third of the nitrogen in poultry wastes exists in the form of uric acid (Fontenot et al.[44]). Burnett and Dondero[45] have shown that 90% of the uric acid is converted to ammonia during seven days of decomposition. The pH rose rapidly during decomposition, from 7.5 to 9.0, because of high ammonia concentrations. These results compare favorably with work done by Stewart[46] with urine from beef cattle. In Stewart's study, urine was added to dry soil regularly and ammonia evolution was measured. He found that 90% of the nitrogen added by the urine was lost continuously after steady state was reached. Another study on the decomposition of poultry wastes was by Flegal et al.[43]. They found that in the storage of poultry wastes only small amounts of crude protein were lost in a month of storage. Some of the discrepancy found may be due to the fact that the manure was fresh and wet and the ammonia produced remained in the manure.

A study by Morrison et al.[47] on decomposition of beef cattle wastes concerns the microbial properties of decomposition. They suggested that decomposition of feedlot manure may be altered by residual antibiotics in the manure. Since antibiotics are more persistent in cooler temperatures, decomposition of manure in winter may be reduced. The various studies presented here and others indicate that decomposition of manure is complex and not well understood.

CHARACTERISTICS OF BEEF CATTLE WASTE

The characteristics of undecomposed beef cattle wastes are important in considering their decomposition rates. This information provides not only an initial starting point from which changes in characteristics occur, but also an insight into the type of decomposition that may occur. The type of characteristics reported also provide indicators for measuring the changes that occur.

Characteristics of beef wastes can be divided into three categories: physical, chemical and microbiological characteristics. Chemical characteristics seem to be most widely reported, possibly because of their major importance to the reuse of the wastes. Table 4 is a collection of common chemical characteristics reported. Of all the constituents reported, nitrogen content is important to nearly every reuse that might be made of manure. Phosphorus, potassium and sulphur are important fertilizer constituents. Sulphur, as an impurity, is also important when manure is to be burned or pyrolyzed. Volatile solids are a measure of the organic matter contained in the manure.

Some chemical characteristics associated with use of manure as a feed are reported. Loehr[48] and Clawson[49] report manure can contain 1.7% to 2.7% fat on a dry basis. Clawson[49] also reports that manure may contain 32% crude fiber and 42% acid detergent fiber; the lower crude fiber due to alkaline soluble lignin being removed (Ward[50]).

Table 4. CHEMICAL PROPERTIES OF BEEF CATTLE WASTES

Chemical Properties, % of dry solids					Water content, % of wet weight	Dry solids production, lbs/day	Source
N	P	K	S	Volatile solids			
3.5	0.52	2.3	--	--	--	--	Salter[54]
3.5	1.0	2.3	0.39	90	80	--	Benne[55]
3.7	1.1	--	--	88	--	9.5-11.4	Taiganidies[56]
3.7	0.46	2.5	--	80	84	10.3	Taiganidies[57]
7.2	--	--	--	87	--	3.6	Witzel[53]
3.5	1.0	2.3	0.43	--	80	--	Loehr[48]
1.9	1.2	2.0	--	76	85	--	McCalla[41]
7.9	1.2	--	--	82	83	7.9	Taiganidies[58]
2.5	--	--	--	85	--	--	Clawson[49]
Number of Values Reported							
9	7	6	2	7	6	5	
Mean							
4.2	0.92	2.2	0.41	84	82	8.54	

Some interest in physical properties of manure has developed in recent years. Properties associated with handling and with drying have been reported. Houkom _et_ _al_.[51] reported thermal characteristics and bulk density at different moisture contents. They found that bulk density decreased with decreasing moisture content from the 85% moisture content level. They also found that thermal diffusivity is nearly independent of moisture content.

Frecks and Gilbertson[52] reported physical properties of beef cattle manure at two different rations. They reported properties including bulk density and particle size distribution. They found bulk density to be independent of the ration fed. The particles in feces from animals fed high concentration ration were finer than those from feces of animals fed high roughage ration.

Microbial properties of beef cattle wastes have been reported. Of importance to this study are data describing the types and relative magnitude of organisms that exist (Miner[32]). Miner reported that 1/4 to 1/3 of the fecal organic matter of ruminants is in the form of microorganisms. Witzel[53] reported that by microscopic count (includes viable and non-viable organisms) 0.25 to 2 billion bacterial cells per gram exist in cattle manure. He also found that 2% to 9% of these cells were viable aerobic bacteria. McCalla *et al.*[41] found 0.18 billion bacteria per ml of a 5% solids manure slurry and only 0.1 million fungi. Of the bacteria 0.3 million were found to be viable anaerobic organisms. These data must be taken in light of a conclusion made by Miner[32]; that the organisms appearing in the wastes are largely influenced by the composition of the feed and the interactions of the microorganisms present with the feed.

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SECTION VI

LABORATORY STUDY ON EFFECT OF ENVIRONMENT ON MANURE QUALITY

GENERAL

Decomposition rates of feedlot wastes have been measured in the field by taking samples over a period of time. This method lacks the flexibility to control environmental conditions. Not only must the wastes be studied over different seasons, transient environmental conditions exist during the ageing. For these reasons a complete field study becomes long and complex. More importantly the effects of environmental parameters are difficult to ascertain. In the laboratory an experiment can be organized where important environmental parameters may be controlled independently. For these reasons a laboratory study was undertaken to determine some of the effects of environment on the decomposition rates of the feedlot wastes.

Decomposition of beef cattle wastes occurs mainly through bacterial action. The factors affecting the decomposition of these wastes are the same factors that affect the growth rates of bacteria. These factors may be divided into three categories:

1. Suitability of the substrate used by the bacteria;
2. The external environment, and
3. The type of bacterial population present.

The factors that compose these conditions are the independent parameters that need to be examined in studying the decomposition of feedlot wastes.

The composition of the wastes, since they are food for the bacteria, are important to growth rates. Composition may be affected by environment or by bacterial action. Water content of manure is a composition parameter which is decreased through drying on the feedlot surface. Change in this parameter occurs mainly as a direct result of the surrounding environment. For this reason and because bacterial growth is dependent on it, water content was chosen as one of the independent variables for this study. Other compositional parameters change more slowly and are affected mainly by bacterial action. For this reason the initial values of these variables are mainly dependent on the particular sample taken. To limit the number of independent variables, a sample representative of average beef cattle wastes was taken. This sample was large and well mixed so that all manure used in this portion of the study would have a relatively constant initial composition.

The type of bacterial population present in the manure is mainly a property of the particular sample of manure. This parameter is therefore fixed as are the other compositional variables.

The external environment of the manure in the feedlot influences the decomposition rate. The temperature of the manure, as affected by its environment, influences bacterial growth rates. For this reason temperature was chosen as an independent parameter. The effect of bacteria-killing radiation was neglected since it influences only the surface of the manure, and the surface is only a small portion of the total volume.

The external environment includes variables that influence the composition of the wastes directly. These include humidity and oxygen content of the air. Humidity affects the water content and is fixed at equilibrium values for water contents modeled. The oxygen content and other components in the air should be similar to feedlot conditions in order to achieve realistic decomposition rates and were assumed to be so in the laboratory air. The physical density of the manure must also be maintained similar to feedlot conditions to provide similar diffusion rates. The density was controlled by compacting the manure as much as possible to simulate feedlot conditions.

The three major independent variables considered are then temperature of the manure, moisture content of the manure, and time. Levels of the temperature and moisture were set at values similar to field conditions. The temperature levels chosen were 120°F, 80°F and 40°F. Since little bacterial action occurs below 40°F, lower temperatures were not selected.

Moisture content levels were set at 70%, 50% and 30%. These levels were selected since they are levels at which decomposition would be expected in the field.

Three levels of temperature and moisture content yield nine different cases to examine with respect to time. Manure for the 120°F and 80°F levels was sampled every other day for ten days, yielding six samples including the initial sample. Manure for the 40°F level was sampled every other day for the first four days and every other day for the 16th through the 20th days, yielding six samples for each case. The longer period of time was used for the 40°F level because a slow decomposition rate was expected.

Methods of measuring decomposition were based on the manure's expected reuse. Decomposition can be viewed in the case of feedlot manure as breakdown and loss of utilizable components. Therefore, the type of use planned for the manure will determine the components measured to monitor decomposition.

Physical and chemical properties were measured and monitored. The physical properties included viscosity, squeezability and odor. The chemical properties included total nitrogen, protein nitrogen, pH, acid detergent fiber (ADF), ash and dry matter. These parameters may be used to describe manure's potential as a feed, fertilizer and fuel.

PROCEDURES AND EQUIPMENT

The methods used throughout this study can be divided into four categories:

1. Collection and preparation of manure;
2. Ageing the manure;
3. Analysis of the manure, and
4. Analysis of the data.

In collection and preparation of the manure, approximately 175 pounds of fresh manure was gathered. The manure was collected from animals of various ages on standard feedlot rations. The manure was collected during a one-day period as the fresh manure was deposited on the feedlot.

After collection the manure was placed in a single batch and well mixed. The manure was then spread on a plastic surface in the shade. A one-half inch layer of the manure was formed and stirred regularly. The manure samples were removed when desired moisture content was reached. The 70% moisture content level was reached within two hours, and the 50% level was reached in 12 hours. The 30% moisture level was reached within 40 hours. The average temperature for the period was near 75°F, and the relative humidity was very low.

After the samples were collected at the various moisture content levels, they were immediately frozen in galvanized pans that would be used later to age the manure. The manure was stored after freezing in sealed plastic bags and stored at 0°F temperature.

As the samples were used, they were removed from cold storage and thawed at room temperature for 12 hours.

Ageing of the manure was done in the galvanized pans in a controlled temperature humidity chamber. After thawing, they were brought to the proper temperature. The initial sample for analyses was taken after the batch reached the proper temperature. The humidity of the chamber was set at a value that would maintain the proper moisture content in the samples. Samples for analyses were taken on the schedule mentioned previously. A two-quart volume was taken at each sampling. The sample was divided in half and one part frozen and stored at 0°F for chemical analysis. The other half of the sample was used for analysis of physical properties and the analysis was done immediately after collection.

Three physical properties were measured on the manure samples: bulk density, viscosity, squeezability and odor. Viscosity was measured on a 15% solids slurry of the manure at a temperature of 26°C. A Brookfield RVT viscometer was used with a No. 3 spindle to measure viscosity. This viscometer rotates a spindle in the manure and measures the resulting torque which can be related to viscosity. Shear rate is then directly proportional to spindle speed. The power law was used to model viscosity which was measured at different spindle speeds. The resulting model is:

$$\mu = K(SS)^n$$

where: K, n = constants
μ = viscosity in centipoise
SS = spindle speed.

Squeezability was performed to evaluate the amount of liquid that could be pressed from a 15% solids slurry of the samples. A potato ricer was used as the press. The ricer used had a 3 inch diameter piston and cup. The cup was perforated with 3/16 inch holes. A 400 g portion of a 15% solids slurry was placed in the ricer and pressed, then stirred until liquid stopped passing the press.

Odor on the samples was noted before performing any of the analysis, but after the sample had been cooled or warmed to room temperature. A note of intensity and of the characteristics of the odor was recorded.

The methods of chemical analysis used in this portion of the study were the same as used in the field study and can be found in that Section.

The data, except for odor, were analyzed statistically. A two-way analysis of variance was performed with respect to temperature and moisture content, with time included as a covariance. Variables that had significant effects were analyzed further for rate of change for each parameter for each temperature and moisture combination. The rates of change for each parameter were compared.

Regression coefficients were computed for each temperature and moisture content combination. This meant that each parameter's rate of change was found for each temperature moisture content combination. A weighted least squares analysis was used and yielded a slope (b) that was assumed to be normally distributed. An F ratio test was then used to test the following hypotheses:

1. That the slope for each temperature (adjusted for moisture content) was the same.
2. That the slope for each moisture content (adjusted for temperature) was the same.
3. That the interaction of temperature and moisture content causes a difference in the slopes.

RESULTS

Significant changes with respect to time were observed in five parameters. Chemical parameters undergoing changes were ammonia, ADF and ash, and physical properties undergoing changes were viscosity and squeezability.

Of the chemical parameters, ammonia underwent the greatest overall change with respect to time, a decrease of 35%. This is relatively unimportant, however, as ammonia is only 3% to 4% of the total nitrogen and 0.05% to 0.1% of the total dry matter. The greatest change in ammonia occurred at a temperature of 120°F (48.8°C) and 70% moisture content as shown in Figure 3.

The change in ADF and ash was significant, but experienced a smaller change on a percentage basis than ammonia. Ash content increased 4% overall with a mean content of 25.6% of the dry matter. Figure 4 illustrates the change in ash at 120°F (48.8°C) and 70% moisture content. ADF increased 3% with a mean content of 34.1% of the dry matter. The change that occurred at 120°F (48.8°C) can be seen in Figure 5.

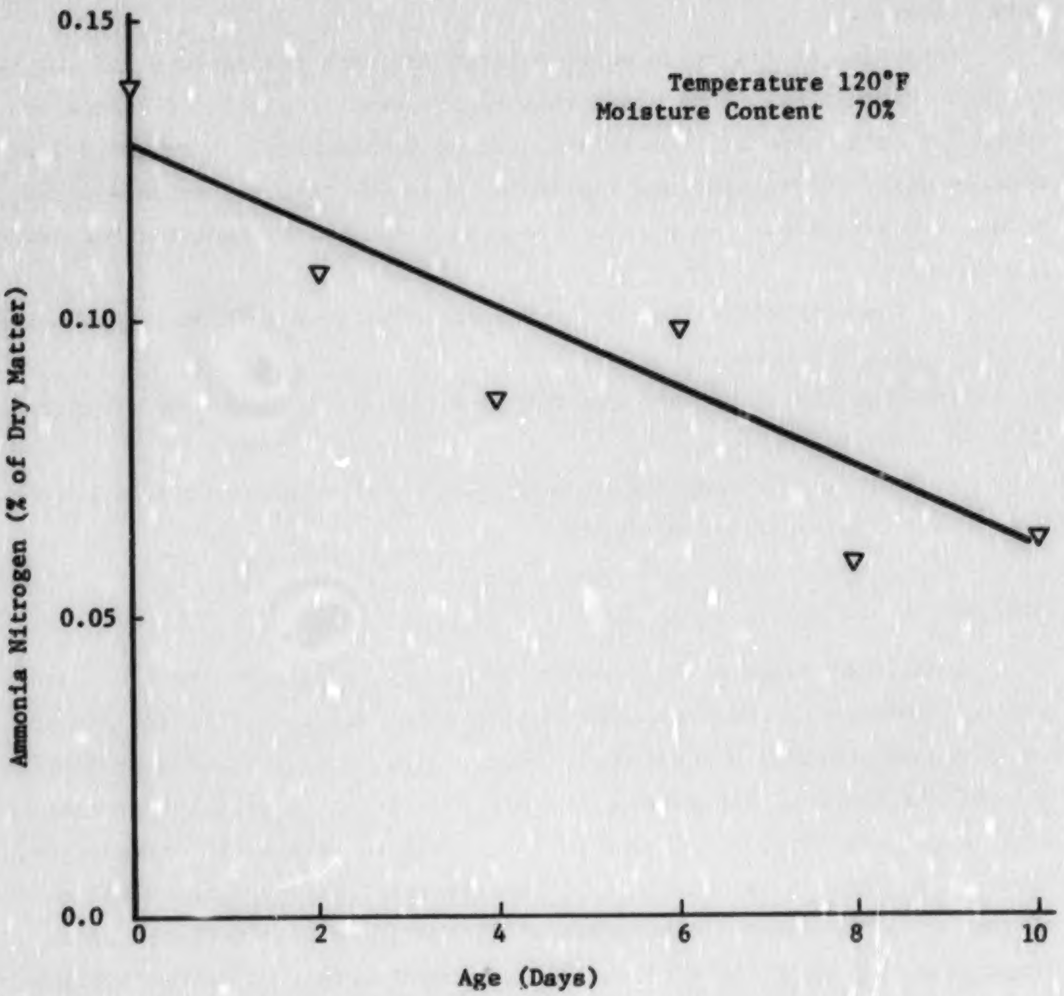

Figure 3. Ammonia nitrogen content of manure aged at 120°F and 70% moisture content

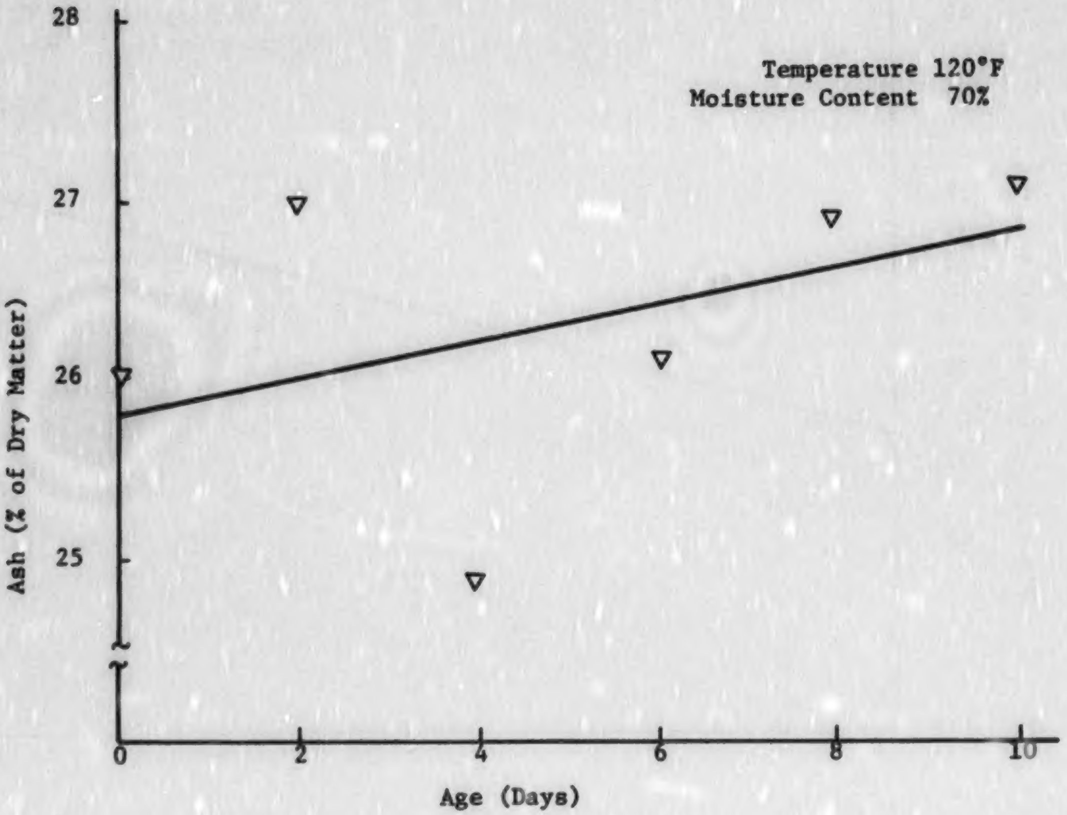

Figure 4. Ash content of manure aged at 120°F and 70% moisture content

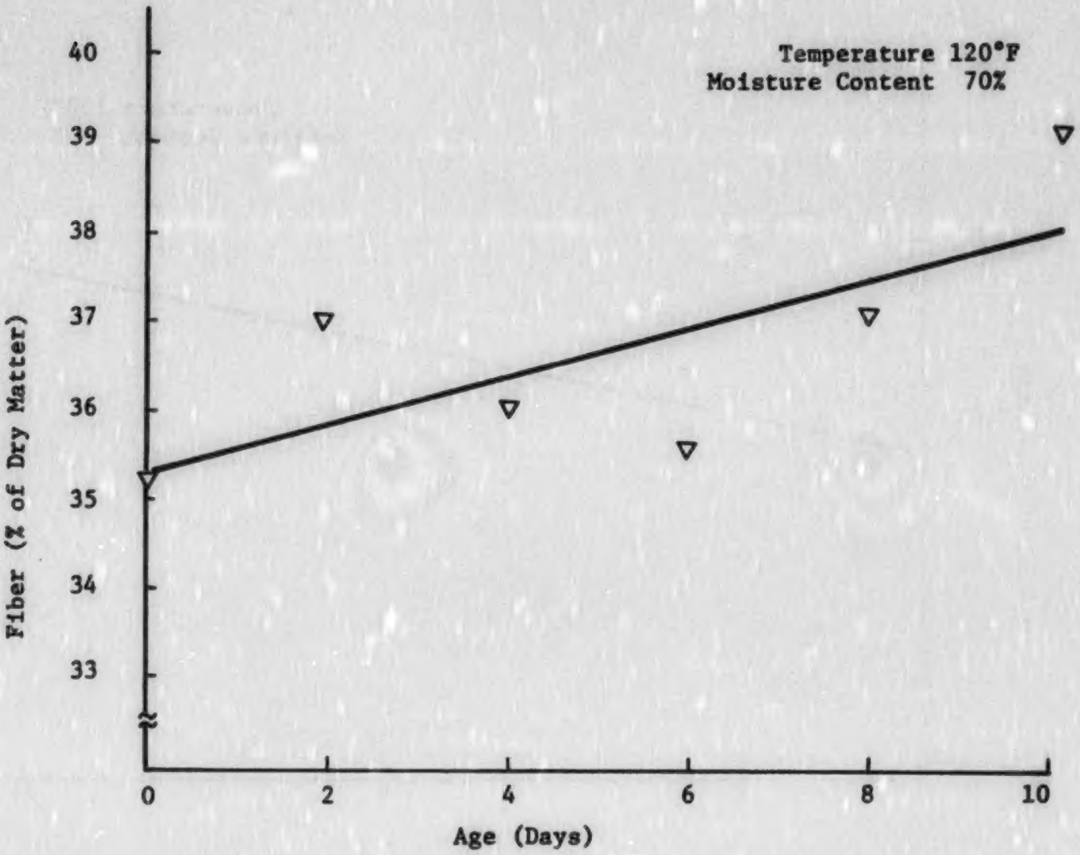

Figure 5. Fiber content of manure aged at 120°F and 70% moisture content

No significant linear trends with time were found in pH, but a pattern in its change occurred. During the 120°F (48.8°C) and 80°F (26.7°C) tests, pH dropped for the first several days, then slowly increased for the duration of the test as shown in Figure 6. This pattern was also observed to correlate with changes in the odor of the manure. During the first several days, a strong silage odor developed and thereafter that odor decreased and was replaced with a strong moldy odor. Mold-like growths were observed throughout the manure during the latter periods of these tests.

Viscosity of the aged manure slurry increased with time. These changes in viscosity can be portrayed as a change in the constant in the viscosity model with time. During the ten- and 20-day tests the overall change was an increase of 50%. Significant differences were found in rates of change of this constant with different treatments. Higher rates of change were associated with higher moisture contents and temperatures. Figure 7 illustrates the absolute value of the viscosity constant for different moisture contents aged at 120°F (48.8°C). The viscosity constant is the actual viscosity of the manure at a particular spindle speed of one on the viscometer.

Squeezability exhibited a 4% overall decrease with time, with a mean of 74% passing through the press. The greatest change in squeezability occurred during the 120°F (48.8°C) and 70% moisture content tests as shown in Figure 8. These changes appeared to be negatively correlated with viscosity. An increase in viscosity would be expected to decrease the amount passing through the press and decrease squeezability.

STATISTICAL ANALYSIS

The statistical analysis of the regression coefficients indicated that the rate of change of five of the eight dependent variables was affected by the independent variables. The unaffected chemical concentrations in the samples were total and protein nitrogen. Rates of change of squeezability were also found to be the same for the different temperature and moisture levels. This occurred though some change could be seen in the previous analysis. The conclusion is therefore that though change in squeezability occurs the different levels of moisture and temperature did not significantly affect these changes.

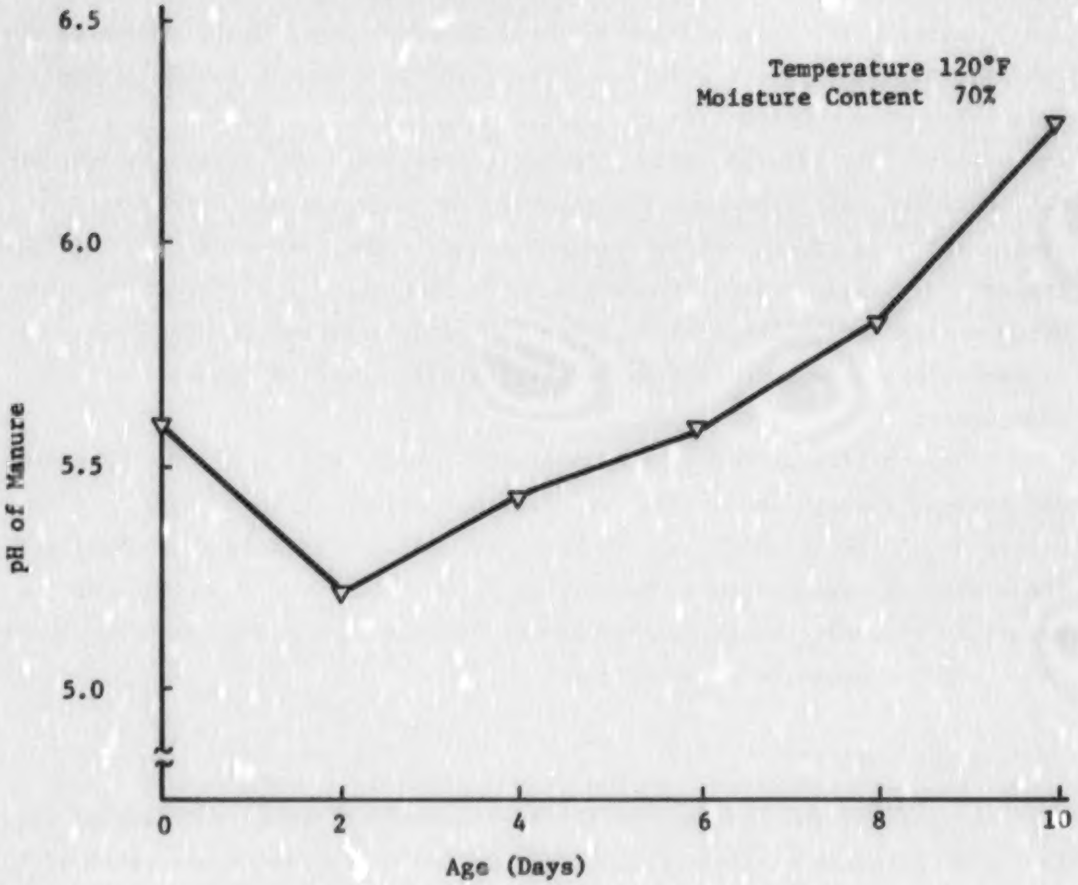

Figure 6. pH of beef feces aged at 120°F and 70% moisture content vs. time

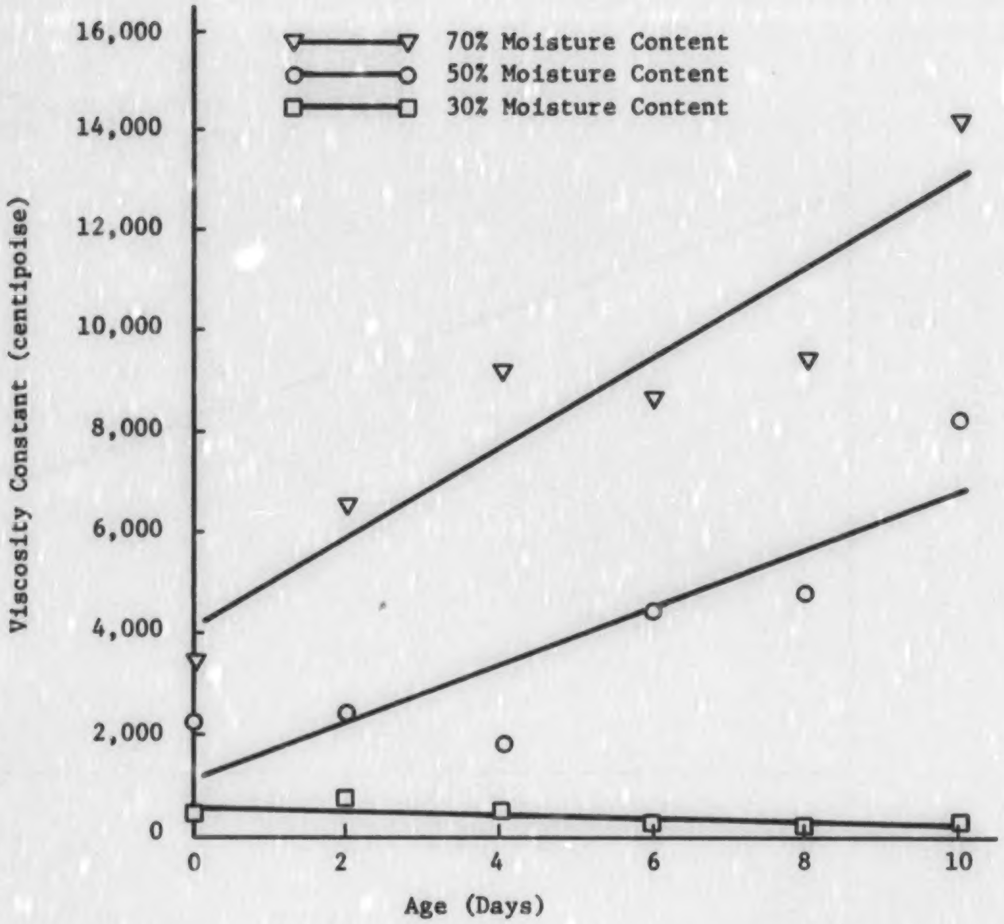

Figure 7. Viscosity constant of beef feces aged at 120°F vs. time

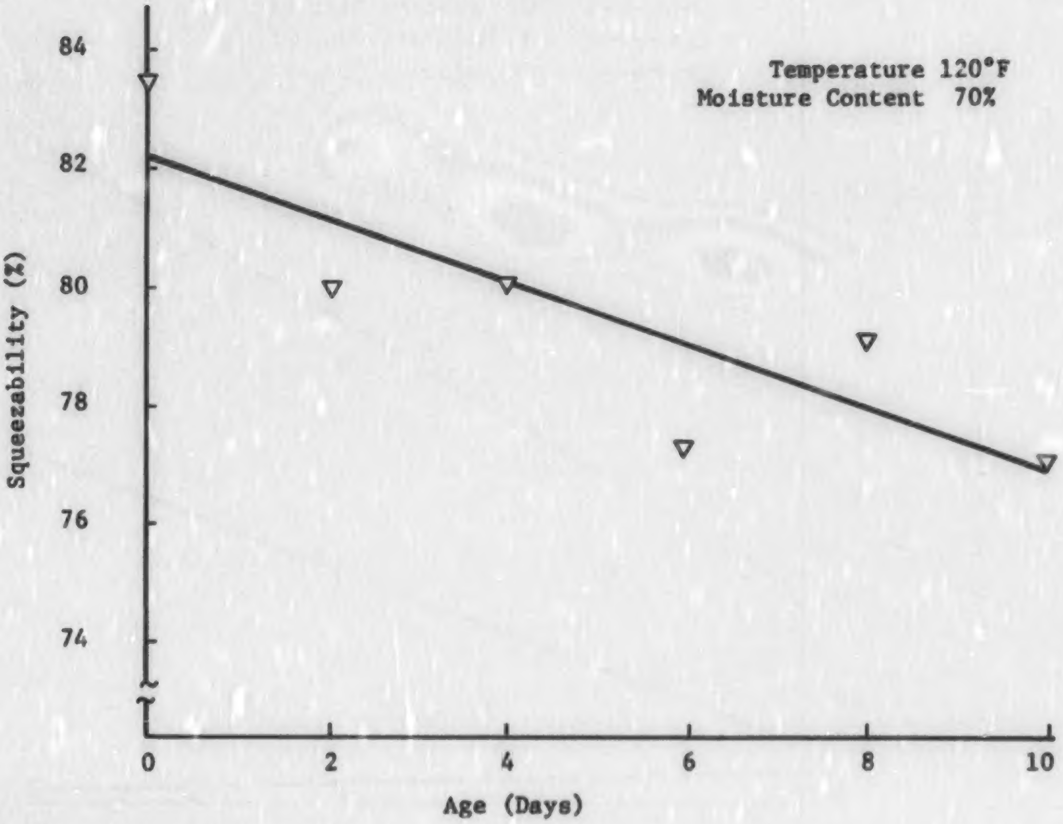

Figure 8. Squeezability of manure aged at 120°F and 70% moisture content

Moisture content and temperature did affect the rate of change of the viscosity constant and exponent, ammonia, ADF and ash. The rate of change of the viscosity constant was found to be increased by higher moisture contents in the ageing manure. The interaction between moisture content and temperature also influenced the rates of change of the viscosity constant. The rate of change of the viscosity exponent was influenced slightly by the interaction of moisture content and temperature. This was caused by one point of the rate of changes and is suspect. There is 7.6% probability that the interaction is not significant.

Ammonia was found to be decreasing at all levels except at the lowest moisture content and highest temperature. Ammonia's rate of change was found to be affected by temperature and by moisture content. Higher temperatures and higher moisture contents seemed to cause greater negative rates of change. At the 30% level of moisture content very small rates of changes were observed at all levels of temperature. The greatest change in odor and appearance of the manure occurred at the higher levels of temperature and moisture content causing greater changes in the manure's chemical properties to be expected here.

Rates of change of ADF were found to be significantly affected by temperature. The rate of increase of ADF was found to increase with temperature. There was 99% probability that the effects were significant. The increases in rates of concentration increase may be due to increasing losses of other components in the manure.

The rate of change of ash increase in the manure was increased by temperature. The probability that there was no significant difference between the rates at different temperatures was 0.07%. The interaction of temperature and moisture content was significant at the 4% level. Ash content may be increased by bacterial decomposition, but even so in some cases it is used as a stable component to base other concentrations on. If this was done the nitrogen components, which showed no change in concentration, would be actually decreasing in total quantities. This effect may be one of the most important changes in the manure.

CONCLUSIONS

Decomposition of manure does not affect the concentrations of total and protein nitrogen in manure, but reuse may be affected by increases in ash and resultant salt concentration increases. Ammonia nitrogen is lost in warm and wet conditions. Management of the feedlot to keep manure dry during hot weather may retard ammonia loss.

Ash and ADF are major chemical constituents in manure. The increase in ash means conversely a decrease in organic matter and suggests shorter harvesting periods, since the 4% increase in this study occurred in ten to 20 days. Increases in fiber concentrations may be important to reuse, and harvesting schedules may be adjusted for the different seasonal temperatures.

Viscosity changes may have a significant effect on manure reuse. Any process that uses slurried manure could develop large increases in viscosity over relatively short periods of storage. To maintain a lower viscosity, shorter harvesting periods may be used, while keeping the manure as dry as possible.

SECTION VII

FIELD STUDY ON EFFECT OF ENVIRONMENT AND MANAGEMENT OF MANURE QUALITY

INTRODUCTION

A major objective of the study was to determine the effects of environment, ration and management on manure quality. This objective can be divided into several areas, the principal ones being the environment of surface that the manure lies on, decomposition of the manure and the ration of the animals that produce the manure.

The type of surface that the manure lies on is a by-product of recycling of the manure. The concrete surfaces are used to facilitate efficient manure harvesting. In most other cases a soil surface is used. In this study one pen was nearly all soil with the exception of a short concrete apron next to the bunk. Both of the other pens used had 70 foot wide concrete aprons next to the bunk. One of these two pens had the manure harvested frequently.

Decomposition of the manure on the feedlot surface causes changes in manure quality. Decomposition is affected by the temperature and moisture content of manure, aside from the other properties of the manure itself. The temperature of the environment and the moisture content of the manure were monitored. The amount of precipitation and the time it occurred were also recorded.

The ration of the animals that produced manure on the feedlots is important in determining the quality of the manure. In feedlots it is customary to start lighter cattle as they enter the feedlot on a ration containing a large amount of forage in the form of silage and/or hay and then increase the amount of grain (i.e. corn) in the ration in a series of ration changes over a period of 30 to 50 days. The practice at the Ceres Land Company feedlot is to use a five step change in rations. The composition of these five rations is shown in Table 5 together with an experimental ration (No. 6) containing a large amount of Cereco silage, a product produced by Ceres

Ecology Corporation from feedlot manure. Cereco silage has a chemical composition similar to corn silage.

Table 5. COMPOSITION OF RATIONS FED TO CATTLE IN CORRALS WHERE MANURE SAMPLES WERE COLLECTED

	Ration number					
Components	1	2	3	4	5	6
	(pounds per ton of feed)					
Corn silage	826	1464	1310	830	662	--
Alfalfa hay	570	106	46	58	32	400
Cracked corn	478	340	546	988	1186	--
Molasses	56	40	44	56	60	60
Starter supplement[a]	70	--	--	--	--	--
Finishing supplement[b]	--	50	54	68	60	60
Cereco silage	--	--	--	--	--	1480
Crude protein, %	12.8	11.0	10.7	11.0	10.8	13.1
Crude fiber, %	19.3	16.4	12.6	8.3	6.5	27.0

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[a] Starter supplement contained 14.4% crude protein.

[b] Finishing supplement contained 27.8% crude protein.

It was anticipated that there would be a correlation between the crude fiber content of rations and the fiber components of the manure samples analyzed. Analyses on feed samples included crude fiber while manure samples were analyzed for the more specific fiber components, cellulose, hemicellulose and lignin, as determined by the ADF and NDF methods. It is apparent from Table 5 that there was a large variation in crude fiber content of the rations from 6.5% to 27.0%.

A relation between crude protein of ration and the nitrogen content of manure would be expected if there were much variation in ration content of protein, but this is not usually the case. The protein content is higher for lighter, younger animals at the beginning of the feeding period, but it can be seen in Table 5 that the protein content varied only from 10.7% to 13.1%.

The quality of manure on the feedlot surface was monitored to determine what changes were occurring. The manure quality was recorded in terms of chemical properties which include parameters describing manure's value as a feed, fertilizer and fuel.

METHODS AND PROCEDURES

The methods used to accomplish the objectives of this portion of the study can be divided into four categories:

1. Sample collection;
2. Weather data collection;
3. Sample analysis, and
4. Analysis of results.

Samples were collected from nine locations, three locations in three pens. A sample was collected near the bunk, near the center and near the back of each pen. Each sample was made of a composite collected in a 10 ft^2 area in the same general locations throughout the study. The manure pack was dug to the manure surface interface so that samples reflect the quality of the consolidated manure pack and not recent buildup. These samples differ from the manure normally scraped from pens, which usually contain more soil-manure material. After collection samples were placed in a polyethylene bag and transported to the laboratory and immediately refrigerated.

Weather Data Collection

A weather data collection station was set up at the Ceres feedlots. On a regular basis temperature, relative humidity, precipitation and average wind speed were recorded. Unsuccessful attempts were made to continuously measure solar radiation and evaporation potential. A United States Weather Bureau data collection station existed within five miles at the Great Western Sugar Company's plant. The data from this station were obtained, compared and used to fill any blanks in temperature records.

Temperature and humidity were recorded on a hygrothermograph. Regular measurements of temperature and humidity were made with a sling psychrometer to serve as a basis for calibration of the recorders. Precipitation was collected in a standard 6 inch rain gauge.

GENERAL LABORATORY PROCEDURES

Preparation of Samples

Mix wet sample thoroughly. Remove one to two pounds and place in drying pan. Dry in 65° oven (drying room) for 48 hours. Remove and let air equilibrate for 48 hours.

Grind in Wiley mill to pass through 1 mm screen.

1. pH -- Read from wet sample with standard pH meter. (May add distilled H_2O as needed.)
2. Dry matter -- Weigh wet sample (about 20 grams) into dry matter tin and place in 105°C oven for 48 hours. Remove and place in desiccator for 30 minutes to cool. Weigh.

   Calculations: $\% \text{ Dry Matter} = \dfrac{\text{Dry (grams) - Tare}}{\text{Wet (grams) - Tare}} \times 100$

Nitrogen Fractions

1. Nitrogen determination (total nitrogen)
   Use the Micro-Kjeldahl procedure according to method outlined by Laitinen, H. A. and W. E. Harris, Chemical Analysis, Second Edition, 1975[59].
2. Protein nitrogen determination
   Weigh 0.1 to 0.2 grams (dry) sample into test tube. Add 2.5 ml of 30% trichloroacetic acid (TCA) solution. Mix thoroughly with Vortex mixer. Let stand for one hour with occasional mixing. Centrifuge for 15 minutes. Decant supernant. Wash precipitate with distilled H_2O. Centrifuge. Decant supernant. Transfer precipitate into Kjeldahl flask using distilled H_2O. Follow Micro-Kjeldahl procedure.
3. Determination of ammonia
   Ammonia, nitrate and nitrite were determined using steam distillation methods as outlined by Bremner, J. M. and D. R. Keeny, Anal. Chem. Acta 32:485-495 (1965)[60]. (This method is used

routinely by the Nitrogen Laboratory of the Agricultural Research Service, U.S.D.A., Fort Collins, CO.)

4. Determination of amino acid nitrogen

Weighed samples were introduced into acid-washed pyrex tubes with 1 ml constant boiling 6N HCl. Using an oxygen-gas flame, a constriction was formed one-third of the way from the top of the tube. The tube was sealed. Hydrolysis occurred in an 110°C oven for 24 hours. The HCl was evaporated under vacuum. The sample was reconstituted with pH 2.2 sodium citrate buffer to achieve approximately a 0.05 to 0.10 µmole amount of each amino acid. Analysis was performed on 1 ml using a single column, accelerated method of Spackman _et_ _al_.[61].

5. Urea-Nitrogen by urease*

   A. Weigh out approximately 0.1 g of sample into Kjeldahl flask.
   B. Add 20 ml distilled H_2O and sufficient urease (based on form and concentration of urease solution). We used a liquid form containing 75 mg/ml to react with 100% of the sample based on sample weight. Allow to set at room temperature (22°C) for 20 minutes and steam distill immediately for 10 minutes. Catch distillate in boric acid (20 g/l) and 2 drops indicator solution (methyl red, methylene blue) (make sure condensor tip is below surface of boric acid-indicator solution). Titrate with dilute HCl.
   C. Run a blank (sample but _no_ urease) with each duplicate set of samples and make correction for the blank.
   D. Calculate mg urea/g sample desired as follows:

$$\text{mg N/g sample} \times \frac{60.0559}{28.0134} = \text{mg urea/g sample}$$

NITROGEN FRACTIONS

Samples were routinely analyzed for total nitrogen, protein nitrogen as indicated by trichloroacetic acid precipitation and ammonia. Non-protein nitrogen was also calculated from the difference between total nitrogen and protein nitrogen. There is no rapid chemical method for determination of true protein while amino acid analyses are expensive. The conventional method is to estimate true protein in a variety of products as the nitrogen precipitable by specific acids. The most commonly used is trichloroacetic acid, although tungstic acid is also extensively used. A recent paper compared trichloroacetic (TCA), tungstic, perchloric and picric acid for precipitation of microbial protein from rumen fluid (Barr *et al.*[62]). Trichloroacetic acid proved to be the most effective. This result is relevant to our work, as a majority of the nitrogen in fecal material is microbial, according to Mason[63]. Knight[64], however, showed tungstic acid to be somewhat more efficient than TCA for microbial protein precipitation.

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*Since no information was available for urea N determination in feedlot manure, this procedure was developed after personal consultation with Dr. Gestur Johnson of the Colorado State University Biochemistry Department.

In order to evaluate the estimates of protein by TCA and tungstic acid precipitation, we made a few comparisons of these estimates with amino acid nitrogen determinations. Amino acid determinations were made on three samples of manure and two samples of a manure-derived product (C-11). The data presented in Table 6 indicates that amino acid N was slightly less than protein estimates by TCA or tungstic acid. Tryptophan, however, was not included because this requires a separate determination for this one amino acid. TCA precipitate tended to be slightly higher than tungstic acid estimates but not significantly so.

Table 6. NITROGEN COMPARISON (mg N/g)

Sample	Kjeldahl-N	TCA-N	Tungstic acid-N	Amino[a] acid-N
CII (4/8)	41.42	21.10	18.56	21.80
CII (6/16)	43.56	23.60	20.16	23.88
Sample No. 8	15.57	9.89	9.41	8.01
Sample No. 114	21.48	13.66	10.90	9.67
Sample No. 153	18.28	10.76	9.61	9.46

[a] Tryptophan is not included in the amino acid analysis.

Nitrate-Nitrogen Analysis

Nitrate-nitrogen levels in feedlot manure were investigated on ten samples randomly selected for analysis. Initial test consisted of a Kjeldahl procedure modified to include nitrate-nitrogen and no significant amounts of nitrate-nitrogen were produced. These results seemed to warrant a more sensitive test which was carried out by the U.S.D.A. Agricultural Research Center under direction of Dr. Lynn Porter and Dr. Fred Norstadt using a Technicon Auto-Analyzer II. Duplicate samples were taken, and extraction of nitrate-nitrogen involved two different procedures: one using an Ag_2SO_4-$CuSO_4$ complex and the other simple distilled H_2O extraction. Analyses from both extraction procedures were similar (Table 7). Expressed in ppm the H_2O extracted samples showed a high of 2.4 and low of 0.74 ppm. Similarly the Ag_2SO_4-$CuSO_4$ extraction showed 2.3 to 0.3 ppm of nitrate-nitrogen. Nitrate-nitrogen in feedlot manure appears to be very low, averaging 1.44 ppm. This is a very small percentage of the non-protein nitrogen (Total N-TCA-N) in these samples. NPN averaged about 10 mg of N per gram of dry sample and NH_3-N about 1 mg-N while 1 ppm of NO_3-N is equivalent to only 0.001 mg of NO_3-N per gram of sample.

Procedure (Jackson[65])*

1. Weigh 5 grams of sample into a 125 ml flask and add 50 ml of extracting solution (dilute 20 ml of 1N $CuSO_4$ and 100 ml 0.6% Ag_2SO_4 to 1 liter).
2. Stopper the flask and shake on a wrist-action shaker for 10 minutes.
3. Stop the shaker, add 0.08g $Ca(OH)_2$, and then shake 5 more minutes.
4. Stop the shaker, add 0.2g $MgCO_3$, and then shake 5 more minutes.
5. Filter the solution through Whatman No. 42 filter paper.
6. Filtrate was analyzed for nitrate-nitrogen using the Technicon Auto-Analyzer II.

Results from this procedure are shown in Table 7.

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*This procedure was repeated with a duplicate sample using 50 ml of distilled H_2O as extracting solution in step 1.

Table 7. TOTAL NITROGEN IN WATER BY KJELDAHL METHOD MODIFIED TO INCLUDE NITRATE

Sample	Nitrate-nitrogen	
	H_2O Extraction, ppm	Ag_2SO_4-$CuSO_4$ extraction, ppm
8	2.4	2.3
30	1.48	1.5
56	1.4	1.4
101	2.16	1.56
114	1.72	2.3
142	1.16	0.9
153	0.74	0.3
181	0.8	0.8
195	1.7	1.9
204	1.06	1.1
Average	1.46 ppm	1.41 ppm

Procedure (Bremner[60])*

1. Weigh 0.1 to 0.2 grams of sample into a clean 100 ml Kjeldahl flask.
2. Add 60 ml digestion acid (dissolve 10 grams of salicylic acid in 600 ml concentrated H_2SO_4), stopper the flask and allow to stand overnight.
3. Add 0.5 grams of $NaS_2O_3 \cdot 5H_2O$ using a long stem funnel. Add 2 boiling chips.
4. Heat cautiously at low heat on the digestion rack until frothing has ceased.
5. Cool the flask and add 2.2 grams of Kjeldahl catalyst (refer to Kjeldahl procedure) and digest the contents of the flask on the

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*Results from this procedure were compared to values for standard Kjeldahl and results are shown in Table 8.

Table 8. COMPARISON OF STANDARD KJELDAHL AND KJELDAHL MODIFIED TO INCLUDE NITRATES

Sample	Standard Kjeldahl, mg N/g	Kjeldahl modified to include nitrates, mg N/g
8	15.53	16.00
30	23.60	22.75
56	20.46	21.10
101	23.22	22.60
114	20.05	21.48
142	29.65	30.98
153	18.99	18.28
181	22.90	23.23
195	31.63	31.66
204	23.32	24.89

digestion rack for 3 hours, swirling intermittently to wash down any particles that stick to the sides of the flask.

6. Cool and add 25 ml of distilled H_2O.
7. Distill according to Kjeldahl procedure.

ANALYTICAL PROCEDURES FOR FIBER FRACTIONS

Neutral-detergent (cell-wall)

1. Weigh 0.1 to 0.2 gram of air-dried sample ground to pass 1 mm or equivalent into a beaker of the refluxing apparatus.
2. Add in order, 50 ml cold (room temperature) neutral-detergent solution, 1 ml decahydronaphthalene, and 0.3 gram sodium sulfite with a calibrated scoop. Heat to boiling in 5 to 10 minutes. Reduce heat as boiling begins, to avoid foaming. Adjust boiling to an even level and reflux for 60 minutes, timed from onset of boiling.

3. Place previously tared Gooch crucibles on filter manifold. Swirl beaker to suspend solids, and fill crucible. Do not admit vacuum until after crucible has been filled. Use low vacuum at first and increase it only as more force is needed. Rinse sample into crucible with minimum of hot (90° to 100°C) water. Remove vacuum, break up mat, and fill crucible with hot water. Filter liquid and repeat washing procedure.
4. Wash twice with acetone in same manner and suck dry. Dry crucibles at 100°C for 8 hours or overnight and weigh.
5. Report yield of recovered neutral-detergent fiber as percent of cell-wall constituents. Estimate cell soluble material by subtracting this value from 100.

Acid-detergent Fiber

1. Weigh 0.2 to 0.3 grams air-dried sample ground to pass 20- to 30-mesh (1mm) screen or the approximate equivalent of wet material into a beaker suitable for refluxing.
2. Add 50 ml cold (room temperature) acid-detergent solution and 1 ml decahydronaphthalene. Heat to boiling in 5 to 10 minutes. Reduce heat as boiling begins, to avoid foaming. Reflux 60 minutes from onset of boiling; adjust boiling to a slow, even level.
3. Filter on a previously tared Gooch crucible, which is set on the filter manifold; use light suction. Break up the filtered mat with a rod and wash twice with hot water (90° to 100°C). Rinse sides of the crucible in the same manner.
4. Repeat wash with acetone until it removes no more color; break up all lumps so that the solvent comes into contact with all particles of fiber.
5. Dry crucible at 100°C for 8 hours or overnight and weigh.
6. Calculate acid-detergent fiber:

$$(W_o - W_t)(100)/S = ADF$$

where: W_o = weight of oven-dried crucible including fiber
W_t = tared weight of oven-dried crucible
S = oven-dried sample weight.

Acid-detergent Lignin

1. Prepare the acid-detergent fiber.
2. Add to a crucible the acid-detergent fiber. Cover the contents of the crucible with cooled (15°C), 72% H_2SO_4 and stir with a glass rod to a smooth paste, breaking all lumps. Fill crucible about half full with acid and stir. Let glass rod remain in crucible; refill with 72% H_2SO_4 and stir at hourly intervals as acid drains away. Crucibles do not need to be kept full at all times. Three additions suffice. Keep crucible at 20° to 23°C. After 3 hours, filter off as much acid as possible with vacuum; then wash contents with hot water until free from acid. Rinse and remove stirring rod.
3. Dry crucible at 100°C and weigh.
4. Ignite crucible in a muffle furnace at 450°C for 8 hours, and then cool and weigh.
5. Calculate acid-detergent lignin:

$$(L \times 100)/S = \text{acid-detergent lignin}$$

where: L = loss upon ignition after 72% H_2SO_4 treatment

S = oven-dried sample weight.

Analytical methods for the fiber fraction followed closely those outlined in the publication: Forage Fiber Analysis[66].

These analytical procedures also allow calculations of additional components as follows:

Insoluble ash (ash insoluble in acid detergent) can be determined by recording the ash resulting from the ashing step in the lignin procedure.

Cellulose = ADF - (Lignin + Insoluble ash)

Hemicellulose (N-uncorrected) = NDF - ADF

Methods for Mineral Analyses

Ash determination was made by ignition in a muffle furnace at 650°C for 8 hours or overnight.

Calcium, sodium and potassium were determined by atomic absorption on wet ashed sample by methods as outlined by Instrumental Methods for Analysis of Soils and Plant Tissue[67].

Phosphorous determination was by the method as outlined in Soil Clinical Analysis[65].

Mercury and cadmium method -- Samples were plasma ashed. The ash was taken up in HCl. The HCl extract is evaluated by atomic absorption spectroscopy by flameless excitation with carbon rods.

PRELIMINARY STUDY OF ANALYTICAL METHODS

A series of four replicate determinations was made at the beginning of the research project in order to evaluate the reproducibility for each method. The results of this investigation are shown in Table 9 and indicate that ash determinations were the most reproducible, followed by Kjeldahl nitrogen. Lignin determinations resulted in the greatest error as a percentage but this was due to the fact that lignin represents a much smaller percentage of the sample.

Routine analyses were performed on duplicate samples and if the difference between samples was greater than 7% the analysis was repeated. As a result, it was necessary to repeat many lignin samples.

Data Analysis

The data collected in the field study included 139 samples of manure. Eighty-four samples had complete chemical analyses and all 139 had all analyses except lignin and ADF insoluble ash. Some samples had mineral and heavy metal analyses. The data that made up the independent variables included the protein and fiber content of the ration, the mean temperature for the period before sample collection, precipitation and location in the pen of the sampling, since these were the properties expected to be most closely related and affected by environmental conditions.

A statistical analysis was performed on the data in order to relate the independent variables, such as location in pen, mean temperature and chemical properties of the ration, to the chemical properties of the manure. A multiple regression analysis was used which revealed any important linear relationships. The squared values of the independent variables were also tested to reveal any relationships with the dependent variables. The statistical analyses were also run on an ash-free basis since error due to sand and dirt, a major part of the ash fraction, could be eliminated.

Table 9. REPRODUCIBILITY OF ANALYTICAL METHODS

Sample No.	Kjeldahl-N		TCA ppt-N		Ammonia		Ash		ADF		NDF		Lignin	
	mg N/g	Max. % difference	mg N/g	Max. % difference	mg N/g	Max. % difference	% Ash	Max. % difference	% ADF	Max. % difference	% NDF	Max. % difference	% Lignin	Max. % difference
12A	21.98		12.63		2.59		40.9		43.1		48.5		6.8	
B	21.67	4.23	12.10	7.35	2.56	3.47	40.1	2.7	41.4	5.69	47.1	4.46	6.0	11.76
C	21.05		13.06		2.50		39.9		43.9		48.1		6.2	
D	21.16		12.73		2.52		39.8		42.0		49.3		6.4	
13A	31.08		17.05		5.13		22.6		24.5		34.0		3.2	
B	29.85	3.96	17.69	9.50	4.88	8.10	22.6	1.7	22.8	9.39	35.4	5.08	3.2	15.79
C	30.28		16.82		5.31		23.0		24.5		34.0		3.3	
D	30.14		16.01		5.21		22.7		22.2		33.6		3.8	
14A	30.35		18.86		4.92		23.8		24.7		34.1		3.7	
B	30.94	2.26	18.19	3.96	4.93	2.96	24.0	1.7	23.6	5.22	36.0	7.84	4.2	17.78
C	30.43		18.94		5.06		23.6		24.9		35.1		4.4	
D	30.24		18.24		4.91		23.9		24.4		37.0		4.5	
15A	19.63		11.84		2.63		45.4		43.9		47.3		3.5	
B	19.85	2.59	11.52	2.95	2.76	4.71	46.7	4.2	44.9	2.66	47.5	3.86	3.9	17.95
C	19.56		11.65		2.71		47.4		45.1		48.4		3.9	
D	20.08		11.87		2.63		47.0		44.4		49.2		3.2	
16A	22.71		14.33		3.56		36.4		36.0		39.2		2.4	8.00
B	23.22	4.58	14.88	7.66	3.69	4.88	37.5	3.7	37.3	3.49	39.0	7.55	2.3	
C	23.69		14.70		3.59		36.5		37.0		39.6		2.5	
D	23.80		13.74		3.51		37.8		37.1		42.4			
17A	27.08		16.57		3.31		30.0		29.4		37.4		3.0	
B	25.45	6.09	16.18	7.54	3.43	6.71	30.7	3.2	27.7	8.28	37.2	8.60	3.1	14.81
C	25.43		15.59		3.20		31.0		29.1		37.5		2.7	
D	25.82		15.32		3.43		30.5		30.2		40.7		3.1	
18A	21.99		14.61		3.17		41.6		35.2		44.2		3.8	
B	21.58	3.41	14.67	6.34	3.04	6.94	40.9	1.7	36.9	6.88	43.0	5.84	3.0	25.00
C	21.89		13.74		3.01		41.3		37.8		44.5		4.0	
D	21.24		14.45		2.95		41.1		37.4		41.9		3.1	

The effect of precipitation on the samples was not analyzed by statistical analysis but by inspection. The precipitation was expected to affect only the moisture content and the ash content due to mixing with mud.

RESULTS

The average composition for all manure samples is presented in Table 10, representing 139 samples (only 83 samples were analyzed for lignin and insoluble ash) collected over a period of one year from three locations in the feedlot and representing six different rations. The data presented here are probably the best averages that one could have for the composition of manure collected from Colorado feedlots. The analyses are also presented on an ash-free basis because ash represents such a large percentage of the samples on a dry weight basis. The overall average for ash was 37.14% and according to location in the corrals ranged from an average of 30.7% to 42.9%. The sampling was made above the obvious soil interface as compared to mechanical scraping which always collects more soil and thus more ash.

All components are expressed as a percentage of dry matter because the dry matter content of samples varied with rainfall and temperature. The overall dry matter percentage was 58.8% and it is interesting that the standard error of this mean was only 1.72, which was no greater than the variation for other organic constituents. As expected, the samples from near the bunk were higher in moisture than those at the rear of the pens.

The analyses presented in Table 11 on dry matter basis are the most representative value for the description of manure that might be harvested from feedlots. However, for comparison of the organic components of manure as harvested, it is probably best to make comparisons on the ash-free dry matter basis and so emphasis will be placed on these values.

Total nitrogen in all samples averaged 3.67% and protein nitrogen as estimated by trichloroacetic acid (TCA) precipitation was 2.35. Ash-free data indicate a slight decrease in the rear of pens in total nitrogen, non-protein nitrogen and ammonia nitrogen, but not TCA-nitrogen, probably indicating some loss of ammonia nitrogen under drier conditions. For all samples, true protein nitrogen represented 65% of all the nitrogen and most of the true protein is probably microbial (Mason[63]). Non-protein nitrogen then represented 35% of the nitrogen and only about one-half was due to

Table 10. OVERALL AVERAGES OF MANURE CONSTITUENTS[a]

% Kjeldahl total nitrogen	% TCA true protein nitrogen	NH_3-N	pH	% Dry matter	% Ash	% ADF	% NDF	%[b] Lignin	%[b] Hemi-cellulose	ADF insol-uble ash	Cellu-lose[b]
Overall Averages of Manure Constituents (% dry matter)											
2.32	1.47	0.31	7.09	58.96	37.14	37.98	45.92	5.31	7.72[b]	21.73[b]	9.63[b]
0.48	0.25	0.15	0.07	1.72	1.01	0.94	0.78	--	--	0.98	--
Overall Averages of Manure Constituents Ash Free (% of dry matter)											
3.67	2.35	0.47	7.09	58.96	--	45.68	55.22	8.58	9.54	--	--
0.38	0.19	0.21	0.07	1.72	--	1.68	1.4	0.49	--	--	--

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[a] Values below means are standard errors of the mean.

[b] Represents only 83 samples.

Table 11. OVERALL AVERAGE BY LOCATION IN THE FEEDPEN (% Dry Matter)

Location	pH	Dry matter	% Total nitrogen Kjeldahl	% True protein nitrogen TCA	% NH_3-N	% Non-protein nitrogen	% Hemi-cellu-lose	% Cellu-lose	% Lignin	Ash	ADF	NDF
All Samples (dry matter)												
Bunk	7.05	53.21	2.61	1.62	0.37	0.99	7.62	28.28	5.25	30.66	33.67	41.42
Center	7.15	63.51	2.28	1.46	0.29	0.82	8.82	31.79	5.26	37.96	38.34	47.15
Back	7.07	60.49	2.07	1.34	0.27	0.74	7.43	34.32	5.41	42.90	43.08	49.46
All Samples (ash-free dry matter)												
Bunk	--	--	3.75	2.34	0.52	0.99	10.86	--	--	--	--	--
Center	--	--	3.64	2.35	0.44	0.82	14.15	--	--	--	--	--
Back	--	--	3.60	2.36	0.46	0.74	12.38	--	--	--	--	--

ammonia nitrogen. About one-fourth as indicated in the methods section, may have been due to urea as indicated by a few samples. The remaining non-protein-nitrogen source is unidentified. The average pH for all samples was 7.34 with little real variation by location.

The fiber components, hemicellulose and cellulose, derived from neutral detergent (NDF) and acid detergent fiber (ADF), can be calculated only on an ash-free basis because there is a large component of acid detergent insoluble ash in the ADF fraction. The calculation of hemicellulose may include a small amount of insoluble nitrogen. The overall average for NDF was 55.2% which represents the percentage of cell-wall material found in the samples. If nitrogen of 3.67 is calculated as protein (X6.25), this would represent 22.9% of the organic fraction. This would be an overestimate of nitrogenous compounds, of course. The lipid content was estimated to be 5% to 7% (Table 16, under lipid analysis). The sum of cell-wall constituents, soluble nitrogenous compounds and lipids would include 80% to 85% of the organic constituents. The remainder would presumably be soluble carbohydrate material. The principal significance of this is that it would be a poor substrate to support microbial growth except for those species capable of utilizing cellulose and hemicellulose, but degradation of these compounds is relatively very slow, compared to soluble carbohydrates.

It is worthy to note that the average lignin value of 8.6% is relatively low and results from feeding mostly high concentrate rations containing only small amounts of lignin. Manure samples from cattle fed starter rations high in forage were significantly higher in lignin.

Correlations Between Components

A complete correlation matrix of components is presented in Table 12 on a dry matter and an ash-free basis. Some of these correlations have no biological significance but the correlations between dry matter, pH and nutrient components would be of interest. However, none of those relations that might be expected to be important (i.e., pH and total N, ammonia N) showed a correlation coefficient not appreciably different from zero.

Interrelation Between Components (Multiple Regressions)

In order to study the interrelationship of the chemical components

Table 12. CORRELATION MATRIXES OF ALL VARIABLES

Variable number	1	2	3	4	5	6	7	8	9	10
				Correlation Matrix of Variables (dry matter)						
1	1.000	-0.377	-0.337	-0.217	-0.006	0.224	0.410	0.241	0.332	0.049
2	--	1.000	0.851	0.841	-0.072	-0.129	-0.834	-0.770	-0.923	-0.239
3	--	--	1.000	0.555	0.046	-0.179	-0.868	-0.710	-0.757	-0.113
4	--	--	--	1.000	-0.108	-0.102	-0.598	-0.644	-0.880	-0.340
5	--	--	--	--	1.000	0.165	-0.109	-0.033	0.089	-0.273
6	--	--	--	--	--	1.000	0.262	-0.002	0.170	-0.201
7	--	--	--	--	--	--	1.000	0.776	0.803	0.121
8	--	--	--	--	--	--	--	1.000	0.793	0.230
9	--	--	--	--	--	--	--	--	1.000	0.289
10	--	--	--	--	--	--	--	--	--	1.000
				Correlation Matrix of Variables (ash-free dry matter)						
1	1.000	-0.377	-0.337	-0.217	-0.006	0.224	-0.410	0.276	0.363	0.162
2	--	1.000	0.851	0.841	-0.072	-0.129	0.834	-0.781	-0.902	-0.482
3	--	--	1.000	0.555	0.046	-0.179	0.868	-0.744	-0.781	-0.385
4	--	--	--	1.000	-0.108	-0.102	0.598	-0.616	-0.797	-0.479
5	--	--	--	--	1.000	0.165	0.109	-0.070	0.018	-0.230
6	--	--	--	--	--	1.000	-0.262	0.011	0.166	-0.058
7	--	--	--	--	--	--	1.000	-0.852	-0.887	-0.444
8	--	--	--	--	--	--	--	1.000	0.830	0.478
9	--	--	--	--	--	--	--	--	1.000	0.521
10	--	--	--	--	--	--	--	--	--	1.000

Legend of Variables for Table 12

Variable number	Variables
1	Location of sample
2	Kjeldahl (total nitrogen)
3	TCA (nitrogen in true proteins)
4	MgO (NH_3-nitrogen)
5	pH
6	Dry matter
7	Ash
8	Acid detergent fiber
9	Neutral detergent fiber
10	Lignin

analyzed, the data were subjected to a multiple regression analysis. Each of the chemical components of manure was studied for its relation to the crude protein and crude fiber content of the ration fed the cattle, the influence of mean daily temperature and location of place where the sample was collected in the pen (i.e., near the bunk, center or rear on a soil surface). Comparisons are presented for samples as collected and on an ash-free basis because ash represented such a large and variable fraction of the manure samples. Those relations that were important as indicated by the R^2 (which indicates the percentage of the variance explained by the parameter(s) included in the regression equation) are presented in Table 13.

Comparison on Ash Basis

The total nitrogen content of manure was related to crude protein of the diet, ambient temperature and location in the pen. The combination of these factors accounted for 31% of the variance in total nitrogen. The indication that nitrogen in manure declines with crude protein (nitrogen) in the feed seems strange but can perhaps be explained in terms of microbial metabolism

Table 13. MULTIPLE REGRESSION COEFFICIENTS AND THEIR RESPECTIVE MULTIPLE CORRELATION COEFFICIENTS

	As Received Basis					Ash-Free Basis				
	Regression coefficients				R^2	Regression coefficients				R^2
	Crude protein	Crude fiber	Tem-perature	Location[a]		Crude protein	Crude fiber	Tem-perature	Location	
Total N[b]	-1.77	--	0.052	-2.80	0.31	--	-0.267	--	--	0.16
Protein N[b]	-0.440	--	--	-1.48	0.21	--	--	0.292	--	0.07
Ammonia N[b]	--	-0.14	-0.03	-0.46	0.41	--	-0.19	-0.05	--	0.38
ADF	--	0.708	--	3.12	0.34	--	0.983	--	5.11	0.34
NDF	--	0.687	--	3.35	0.63	--	0.957	0.269	5.67	0.57
Lignin	--	0.09	--	--	0.11	--	0.233	--	--	0.17
pH	--	-0.224	-0.0773	--	0.21					
Dry matter	--	--	0.61	3.71	0.36					
Ash	6.17	-0.719	0.158	6.52	0.33					

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[a] Location was coded as: 1 - Bunk, 2 - Center of pen, and 3 - Back of pen.

[b] Nitrogen contents are given in the equations presented as Mg/g dry matter, which is 10 times the percent N on a dry matter basis.

in the rumen and cecum. The same factors accounted for 21% of the variance in protein (TCA) nitrogen. Ammonia-N variance, on the other hand, of 41% is explained by a combination of temperature, location and crude fiber content of the ration. The relation with crude fiber of the ration is difficult to explain. Samples declined in all nitrogen from front to rear of the pens.

The fibrous components of manure, ADF, NDF and lignin, were related to the crude fiber content of the ration, as would be expected. NDF is a measure of plant cell-wall material and ADF of the plant cell-wall constituents, cellulose and lignin. NDF minus ADF represents essentially hemicellulose. Hemicellulose is a term for a diverse group of non-cellulose, carbohydrate polymers of which pentosans are probably the most important. Cellulose and hemicellulose, but not lignin, are degraded by fecal bacteria under anaerobic conditions. Degradation can continue in the manure so long as conditions of temperature, moisture and anaerobiosis are adequate. As the percentage of NDF and ADF increase, the percentage of components soluble in these reagents increase and these soluble components are those most readily degraded by bacteria. Only 11% of the variance in lignin was associated with the factors that were studied.

The pH of samples was associated with crude fiber of the ration and temperature. The pH was also related quadratically to temperature and crude fiber. A high crude fiber content probably means less soluble carbohydrates which are the source of organic acid. However, a decrease in temperature was associated with an increase in ammonia which should involve an increase in pH.

Dry matter of manure was related to temperature and location in the pen; the combination accounted for 36% of the variability. The location at the rear of the pen allows more time for drainage into the soil. The ash was strongly associated with location, slightly related to crude fiber and temperature but closely related to the crude protein content of the ration for reasons that cannot be explained.

Comparison of Ash-Free Basis

It is apparent from Table 13 that making these same calculations on an ash-free basis did not improve the R^2 values as anticipated; in fact, in general the R^2 is less although not significantly so than when compared with the original sample. Although an ash-free expression is desirable for comparison of the chemical or nutritive properties, the calculation would not be expected to change the correlations although actual numbers in the regression equations would change.

Mineral Analysis

A total of 63 samples were analyzed for P, K, Ca and Na by the Colorado State University Soil Testing Laboratory by the methods described above. The results are summarized in Table 14, together with the value for total nitrogen in the same sample since N, P and K are elements of greatest interest when manure is considered for fertilizer. The concentration of N, P, K and Na were slightly higher in samples collected near the feedbunk and progressively lower at the center and rear of the pen, while Ca concentrations did not fit this pattern. The differences, however, are not statistically significant, as indicated by the magnitude of the standard deviations, even though the trend indicated is what would be hypothesized on the assumption that samples toward the rear of the pen would contain more soil in which the concentration of elements (i.e., Fe, Al) would dilute the concentration of the elements discussed here. The results presented differ some from the limited data available for comparison (Azevedo and Stout[68] and Ede and Branson[69]), but conditions of collection, ageing, weathering, etc., were not uniform.

Trace Element Analyses

Nine samples were selected at random and analyzed for lead (Pb) and cadmium (Cd). The results are presented in Table 15. Westing and Brandenberg[70] reported an average for Pb of 12.7 and 0.61 for cadmium in feedlot manure. Samples containing 8.5 ppm and 5.5 ppm of cadmium might be of concern, but those particular samples were both collected near the feedbunk, yet represented two different rations, and we have no explanation for these higher levels.

Twenty samples have been submitted for analysis by X-ray diffraction analysis to the Lawrence Livermore Laboratory, Livermore, CA. A study has been completed to determine the effect of processing by lyophilization, oven drying and ashing. The dry sample produced similar results to the freeze-dried sample except for considerable loss of bromine which was not of great

Table 14. MEAN CONCENTRATION OF PHOSPHORUS, POTASSIUM, CALCIUM AND SODIUM IN MANURE SAMPLES BY LOCATION IN PENS (% of dry weight of samples)

No. of samples	N	P	K	Ca	Na
			Near the Feedbunk		
22	2.63 (0.45)[a]	0.58 (0.11)	1.60 (0.30)	1.77 (0.24)	0.58 (0.08)
			Center of Pen		
21	2.23 (0.58)	0.52 (0.12)	1.19 (0.32)	1.91 (0.44)	0.46 (0.12)
			Rear of Pen		
20	2.02 (0.56)	0.50 (0.13)	1.24 (0.29)	1.98 (0.23)	0.48 (0.13)
			Mean of All Samples		
63	2.29 (0.50)	0.54 (0.12)	1.35 (0.30)	1.88 (0.31	0.51 (0.10)

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[a] Standard deviation of the means.

interest. Mean values from preliminary analyses indicated the following in mg/kg (ppm): Mn 131, Fe 2736, Cu 35, Zn 92, Br 35, Rb 24, Sr 114, Zr 84 and Pb 19. Analyses have not been completed but results are expected soon.

Interpretations of Mineral Analyses

The primary fertilizer elements, N, P and K, were present in a ratio of about 4:1:2 which would provide a generally useful fertilizer. The average quantity per ton of dry manure would be 46 lbs N, 11 lbs P and 27 lbs K. The concentration of Ca at 40 pounds per ton is not of interest for application to the arid soils of the West but would be in the humid areas of the country. The Na concentration varied little between samples, probably indicating a rather constant Na intake by the cattle. Na, as a possible pollutant at 20 pounds per ton, is also to be considered.

Although the ash content of manure varied from 30.7% to 42.9% of the dry matter, the concentration of the elements shown in Table 15 varied much less. This probably means that those elements arising from feed are present in a rather constant proportion while those making up the gross ash fraction

Table 15. CONCENTRATION OF LEAD (Pb) AND CADMIUM (Cd) IN RANDOMLY SELECTED MANURE SAMPLE (ppm)

Sample No.	Pb	Cd	Sample No.	Pb	Cd
8	3.0	<0.5	114	2.2	1.5
14	1.5	1.5	118	1.5	1.0
23	1.5	5.5	121	3.0	4.0
32	2.2	1.0	132	2.2	0.5
41	0.7	1.0	136	3.0	0.5
42	0.7	2.0	145	2.2	<0.5
56	2.2	2.5	150	0.7	0.5
63	2.2	>8.5	153	1.5	0.5
65	2.2	3.0	163	2.2	<0.5
71	3.0	1.5	172	1.5	<0.5
76	2.2	2.0	176	1.5	<0.5
103	1.5	1.5	184	1.5	0.5

represent variable fractions of soil minerals (i.e., silicon and aluminum, which were not determined). Chlorides are important anions which were not included in the analyses.

LIPID ANALYSIS

Lipid analysis was not included in the protocol for this experiment because it was known that the lipid content would be low and of diverse chemical composition, representing as it does either indigestible non-fat lipids from forage or from cattle fed high concentrate rations. The lipids are primarily metabolic fecal fat originating from the bile to a large extent.

Twelve samples of manure were selected at random and two lipid analyses were determined using the Bailey-Walker extraction equipment. In the first analysis a chloroform-methanol (2 to 1 v/v) solvent was used. This solvent extracts the more water soluble phospholipid fractions in addition to other lipids. In the second analysis hexane was used as the solvent. Results of both solvents are presented in Table 16. The chloroform-methanol solvent indicated an average lipid content of 7.07% with a range of 4.29% to 9.64% while the hexane solvent indicated an average lipid content of 4.98%, with a range of 2.83% to 6.15%. These levels are much higher than those found by Lucas et al.[71] or by Ward[72] for fresh steer feces and higher than found by Johnson[73] for scraped feedlot manure. No explanations are apparent to explain these levels higher than previously reported.

WEATHER AND COMPOSITION

Some changes in manure properties were observed to be related to rainfall. During two consecutive sampling periods (days 228 and 241), 5.2 in. of precipitation were received. A decrease in dry matter in the manure would be expected and was observed. Ash content might be expected to increase due to more mixing with soil but was observed in only one case. Ash content increased in one position where water stood in the pen for two weeks. Manure from this position was charcoal-like and contained large amounts of soil.

Cellulose and non-protein nitrogen were the only other variables to show obvious changes. Cellulose content was increased during these wet periods and non-protein nitrogen was decreased.

CONCLUSIONS

Ash represents a large percentage of the composition of all manure samples. Overall average was 36.2% with a range from 30.7% to 42.9%. Ash content was lowest on surfaced areas of pens.

The total nitrogen content of the manure was related to the crude protein content of the diet, ambient temperature and location in the pen. The combination of these factors accounted for 31% of the variance in nitrogen.

The primary fertilizer elements, N, P and K, were present in a ratio of about 4:1:2 which would provide a generally useful fertilizer. The average quantity per ton of dry manure would be 46 lbs N, 11 lbs P and 27 lbs K. A concentration of 40 pounds Ca per ton would be of value in some types of soil.

Little variation was found in the Na concentration, and its relationship to other mineral elements was nearly constant. The average quantity of 20

Table 16. SOLVENT EXTRACTABLE LIPID FROM MANURE SAMPLES

Sample No.	Chloroform-methanol solvent, % lipid of dry matter	Hexane solvent, % lipid of dry matter
8	6.02	5.04
42	7.94	5.68
65	7.01	5.38
76	6.06	4.47
114	7.46	4.50
121	9.64	6.15
132	7.56	5.38
153	6.89	6.13
163	8.38	4.80
176	4.29	2.83
181	7.84	5.20
184	5.70	4.24
Total average	7.07%	4.98%

pounds Na per ton of dry manure should be considered in regard to accumulation with continuous applications of manure for fertilizer.

The fibrous components of manure, ADF, NDF and lignin, are related to the crude fiber content of the ration. NDF is a measure of plant cell-wall material and ADF of the plant cell-wall constituents, cellulose and lignin. NDF minus ADF represents essentially hemicellulose, a diverse group of non-cellulose, carbohydrate polymers. NDF value for overall manure constituents averaged 45.92% of dry matter.

Cellulose and hemicellulose are degraded very slowly by fecal bacteria under anaerobic conditions; therefore, the fibrous components are important if the manure is to be used for methane gas production.

High temperatures result in an increased ash and fiber concentration and a decreased ammonia concentration; therefore, more frequent harvesting is recommended during periods of high temperatures (summer).

RECOMMENDATIONS

The ash content in manure used for recycling represents unusable material; therefore, a low ash content is desirable. The ash content contributed by dirt mixed into the manure can be reduced by utilizing surfaced pens. Ash content in manure from surfaced pens should be approximately two-thirds of that found in good unsurfaced pens.

Recycling manure for protein recovery will be most successful on surfaced areas next to feedbunks where high concentrate rations are used.

Average fertilizer contents for feedlot manures from typical operations under Colorado conditions are: 46 lbs N, 11 lbs P and 27 lbs K per dry ton.

Methane gas production or pyrolysis will utilize the carbon components in manure from rations containing high crude fiber contents.

More frequent cleaning is recommended during the summer months to reduce losses from decomposition and reduce excessive buildup of ash. High moisture together with high temperatures will result in most rapid decomposition. Similar losses will occur in stockpiles of wet manure.

Collection periods of no more than one month are recommended under these conditions for recycling purposes.

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SECTION VIII

RUNOFF CHARACTERIZATION

GENERAL

Hard surfacing and more frequent cleaning schedules will be a departure from more conventional feedpen management methods. In conjunction with the use of new manure harvesting techniques, there will be an effect on feedlot runoff pollution potential.

This study was made to determine whether these changes are positive or negative, in terms of pollution abatement, including a determination of the effects frequent feedpen cleaning and the surfacing of the feedlot floor have on the pollution potential of the feedlot runoff.

BACKGROUND INFORMATION

The major pollution problem presented by a feedlot is the rainfall, or other precipitation, which comes in contact with the manure, then runs off carrying high concentrations of oxygen-demanding materials, solids, nutrients and disease organisms into surface waters and sometimes leaching into the ground water.

In past studies temperature, the moisture content of the manure mantle before a storm, the rainfall intensity and duration, and physical feedpen characteristics (pen floor base, surface, etc.) have been found to influence the quality of the runoff. It has been found warmer temperatures are accompanied by higher organic matter concentrations in the runoff. Miner[74] suggests the increased solubility, or rate of solubility, of the soluble solids in warmer water may be the reason.

Initial moisture content of the manure pack (i.e., the percent of water contained in the manure per unit weight prior to a storm) has been indicated as being important in runoff characteristics. Dry manure surfaces generally have more surface storage available to store precipitation than do wet manure mantles. Also, wet manure packs hold high concentrations of dissolved organic matter at the onset of rainfall. Management, especially in arid locations, can to some extent control the moisture level of the feedlot surface by varying the stocking rate.

Rainwater from a low intensity, long duration rainfall has a long period of contact with the manure and thus carries a high concentration of organic matter and nitrogen when it does run off. With heavier rainfalls, the water starts to run off sooner and does not have as much time to dissolve material on the feedpen surface.

The thickness of a manure pack is a function of management practices. A thick manure pack, while containing more water per unit area than a shallow pack, may have more storage capacity available than do the thinner packs. This is possible because the volume of manure on the feedlot surface is more when the manure mantle is deep (e.g., a 4-inch manure mantle has twice the volume of a 2-inch manure mantle). Therefore, even with the concentration of dissolved organic matter present in a thick manure pack, the thick manure pack may offer less pollution problem than a thin pack for some rainfall occurrences. The infiltration rate of the manure and the anticipated rainfall intensity would need to be considered to determine the optimum manure mantle depth for minimizing pollution.

Flat feedlot surfaces allow a longer time for the rainwater to be in contact with the manure before running off the feedpen surface. Consequently, the runoff tends to contain higher concentrations of dissolved materials than runoff from steeper lots. On the other hand, assuming no indentations in the surface, runoff from steeper lots will have a greater velocity and will contain more suspended solids.

Studies by Wells _et al._[75] indicate ration to have very little effect on the concentration of runoff. Depending on the factors involved, between one-third and one-half of all moisture falling on a feedlot eventually leaves as runoff. In the process, one to six percent of the material deposited on the feedpen floor leaves with the runoff. The composition of the manure itself then is reflected in the runoff. The manure, however, is dependent on the ration fed the beef animal, which means the ration also is reflected in the runoff contents.

Pen surfaces can be either unsurfaced, partially surfaced or totally surfaced. Advantages and disadvantages exist for each of these pen surfaces, depending upon site specific conditions. Since the main concerns in this study are the effects of frequent manure harvesting on the feedlot pollution potential, the positive and negative aspects will be discussed with this in mind. To guard against ground water contamination and mixing of soil with the manure, Shuyler _et al._[76] suggest three to four inches of the manure should be left on the floor of a dirt feedpen. This requires careful removal of the waste.

As seen from Table 17, concrete or surfaced pens allow higher stocking rates. Solid wastes may be removed from the concrete floor without concern for ground water contamination or sloppy pen conditions. Another advantage is the reduction of runoff from the surfaced feedlots on a per animal basis, a result of the higher stocking densities.

The above discussion presents some of the variables affecting feedlot runoff quantity and quality. The variables must be considered collectively when trying to make determinations of runoff pollution potential, even though the main concern is the depth of the manure mantle and the kind of surface used for the feedlot floor. These independent variables considered in this study are summarized in Table 18.

Table 17. SUMMARY OF STOCKING RATES FOR OPEN FEEDLOTS[76]

Lot Surface	Stocking Rate
Unsurfaced	
Dirt, medium textured soil	200-300 sq ft/animal
Dirt, poor drainage on heavy soil	300-400 sq ft/animal
Partially surfaced	
Concrete slab in front of feedbunk	100-150 sq ft/animal
Surfaced	
Concrete	50-70 sq ft/animal

Table 18. INDEPENDENT VARIABLES FOR RUNOFF STUDY

Variable	Alphanumeric symbol
Rainfall intensity, cm/hr	ARI
Surface type, (1 = concrete; 2 = dirt)	ST
Surface slope, percent	SS
Manure mantle depth, cm	DMM
Initial moisture content, percent (wet basis)	BMC
Ration, (concentrate to roughage ratio)	R
Time, hour	T
Total rainfall, cm	TR

TESTING CONSIDERATIONS

Following the establishment of the factors which affect feedlot runoff pollution potential, it must be determined what effects are of concern on the resultant pollution potential. The important factors related to runoff quality have been determined, to a large extent, by previous water quality analysts. Pollutants entering a body of water affect water quality and its usefulness.

In determining the quantity of runoff coming off a feedpen area, the variables of concern are empirically established. The volume of feedlot runoff from individual rainfall events must be known for proper sizing of facilities. The principal factors of concern include:

1. The amount of rainfall stored before runoff occurs;
2. The rate at which collection and retention facilities must handle the runoff, and
3. Total volume of runoff to expect from a feedlot area.

The dependent variables to be considered are summarized in Table 19.

PROCEDURES AND EQUIPMENT

The project plan included a quantitative and qualitative determination of feedlot runoff as experienced with the type of conditions and management used

Table 19. DEPENDENT VARIABLES FOR RUNOFF QUALITY AND QUANTITY DETERMINATIONS

Variable	Alphanumeric symbol
Biochemical oxygen demand, mg/l	BOD
Chemical oxygen demand, mg/l	COD
Settleable solids, ml/l	SSLDS
Volatile solids, mg/l	VSLDS
Inorganic solids, mg/l	ASH
Total alkalinity, mg/l$CaCO_3$	ALKLN
pH	PH
Time to runoff, hour	TRF
Accumulated rainfall to runoff, cm	ARRF
Runoff rate, cm/hr	RFR
Accumulated runoff, cm	ARF
Resulting runoff, percent	RRF

with frequent manure harvesting. Data to predict runoff quality and quantity were to be obtained from a combination of data from natural precipitation and simulated rainfall.

Runoff measurement flumes and weather data recording equipment were installed in the three pens used in the study.

Runoff from natural precipitation occurred from only one storm event; therefore, no usable data were obtained from the natural precipitation and only that from the simulated rainfall were usable for analysis.

Rain Simulation Equipment

The field equipment used for rain simulation in the runoff studies consisted of the artificial rainfall equipment and the sample and runoff collection unit. It included a trailer-mounted pressure pump, recirculation pump and tank, sprinkler unit and collection apparatus.

The sprinkler head was partially shielded so water would be sprayed out for only part of the sprinkler rotation. The water collected within the shielded portion of the sprinkler's rotation was pumped back to the recirculation tank. Valving was such that any desired pressure could be maintained at the sprinkler nozzles. The intensity of the simulated rainfall could be varied by changing nozzles on the head, pressure and sprinkler head rotation speed.

Runoff Collection

The test plot was separated from the rest of the feedpen floor by 10 cm (4 in.) sheet metal boundaries. The plot had dimensions of 1.2m X 2.4m (4 ft X 8 ft) with the length being parallel to the slope of the feedpen floor and with the direction of spray from the sprinkler head.

At the lower end of the plot, runoff water was funneled into a collection tank of known dimensions. Samples for water quality determinations could be collected before the runoff was drained into the tank. Runoff was retained in the tank to determine the volume of runoff occurring from the rainfall event. The depth of runoff collected with respect to time was recorded by a Stevens water level recorder. Knowing the cross-sectional area of the collection tank and the depth of the water collected, the quantity of runoff was determined.

Runoff Quality Analysis

Samples of 2.1 litre were collected for water quality analysis. The first sample of the test run was taken when there was visual sign of runoff. The second sample was taken approximately 0.5 hr after the start of runoff. The third, fourth and fifth samples were collected at 1.5, 3.5 and 5.5 hr intervals after the start of runoff, respectively, or the final sample just prior to the end of the rainfall event.

To preserve samples for laboratory analysis, they were placed in an ice bath immediately after collection. To further preserve the samples for COD analysis, 5 ml of concentrated sulfuric acid was added to the 250 ml samples. Laboratory analysis was done on all samples less than 35 hours after collection. At the laboratory, the samples were warmed to room temperature before analyses were conducted. Standard methods were followed for all water quality analysis.

Nine test runs were conducted. Four of these were on concrete surfaces. For each test run on a concrete surface there was a corresponding run on a dirt surface. A series of tests were selected to correspond to rainfall events with low, medium and high intensities on both concrete and dirt feedlots and for thin and thick manure mantles. Tests were conducted on concrete with thin (<2.0 cm or 1.3 in.) manure packs and dirt surfaces with thicker (4.3 cm or 1.7 in.) manure packs. Included in the testing scheme were prewetting runs on the concrete and dirt surfaces to simulate two-day rainfall events. Further specifics are listed in Table 20.

ANALYSIS AND RESULTS

A computer program (STAT38R) in the statistics file at the Colorado State University Computer Center was used to run regression analysis on the data collected. This program computes a sequence of multiple linear regression equations in a forward stepwise manner. At each step, one variable is added to or deleted from the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Also, it is the variable which has highest partial correlation with the dependent variable partialed on the variables which have already been added.

Data reduction and analysis were also done by making visual interpretations of the raw data and averages of collected data. The following are statistical and visual interpretations of data obtained from the simulated rainfall tests.

Runoff Rate (RFR)

The dependence of the runoff rate upon the intensity of the rainfall which is being applied is shown in Equation 1 of Appendix B. The linear regression equation does not indicate a point at which the runoff rate will approach the rainfall intensity. It is known, however, that there is such a point at which time the feedlot floor is saturated and the water intake rate is negligible. If runoff rate versus time is plotted for a particular run, as shown in Figure 9, this is demonstrated. The rate of runoff starts low and approaches the rainfall intensity asymptotically.

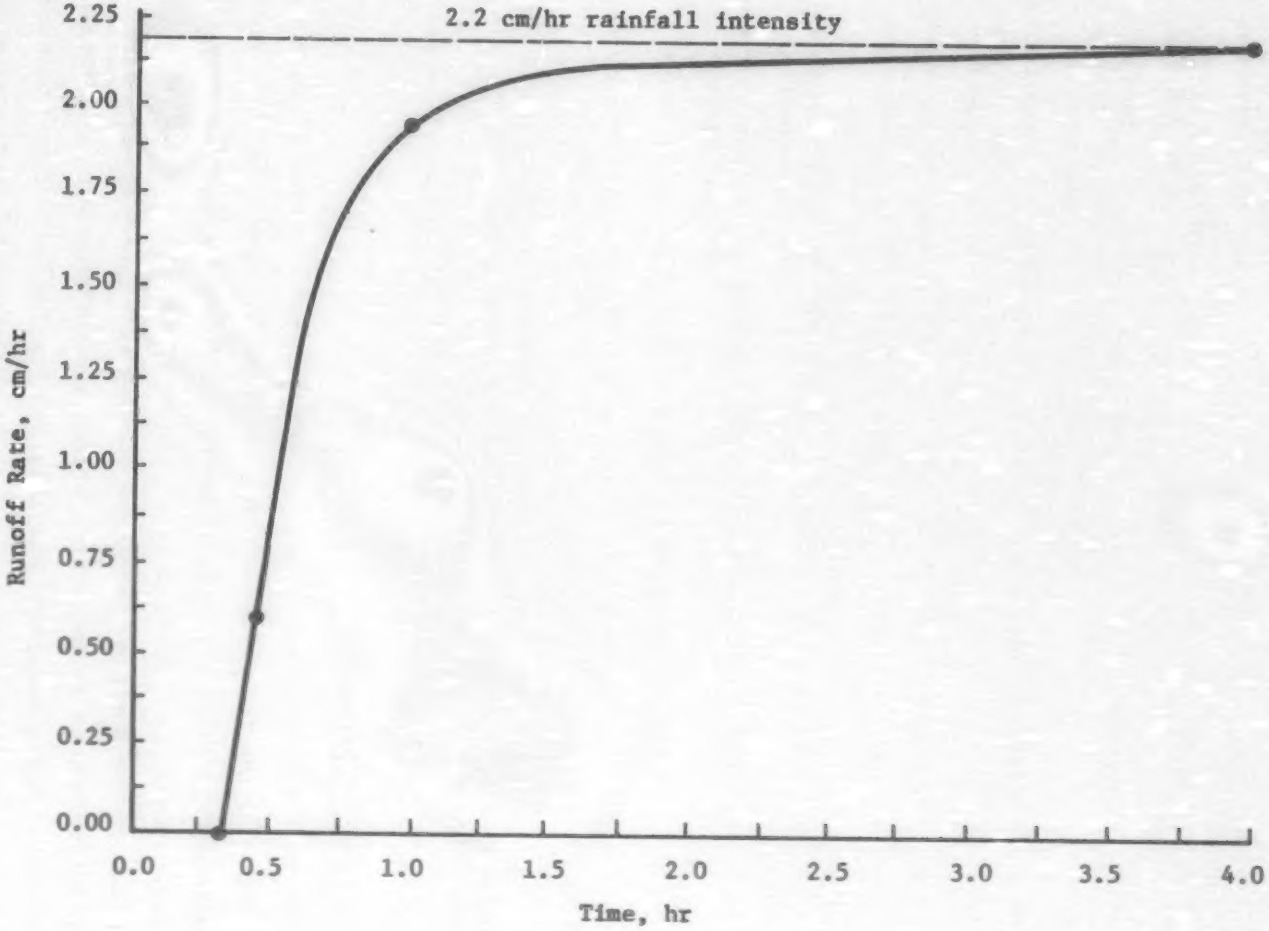

Figure 9. Time-runoff rate relationship for test run 2

Table 20. PRE-STORM FEEDLOT SURFACE CONDITIONS

	ARI, cm/hr	ST	SS, %	DMM, cm	BMC, %	R	Location
Run 1	4.2	Concrete	1.7	1.8	12.0	5.25	On edge of concrete apron: approx. 20 ft from waterer and 70 ft from feedbunk
Run 2	2.2	Dirt	0.8	2.3	7.3	5.25	Approx. 40 ft from waterer and 40 ft from feedbunk
Run 3	1.9	Concrete	2.7	1.3	5.4	3.31	Edge of concrete apron, 20 ft from waterer and 70 ft from feedbunk
Run 4	0.4	Concrete	0.5	1.3	10.9	3.31	Edge of concrete apron, 20 ft from waterer and 70 ft from feedbunk
Run 5	2.8	Concrete	0.5	2.0	61.2	3.31	Same plot as Run 4
Run 6	1.9	Dirt	2.5	4.3	22.4	0.25	70 ft from waterer and 40 ft from feedbunk
Run 7	3.7	Dirt	1.6	4.3	15.0	0.25	50 ft from waterer and 40 ft from feedbunk
Run 8	0.4	Dirt	2.0	4.3	24.6	0.25	20 ft from waterer and 50 ft from feedbunk
Run 9	2.8	Dirt	2.0	4.3	58.9	0.25	Same plot as Run 8

Test Runs 5 and 9 were conducted the day after the feedpen surfaces were wetted by Runs 4 and 8, respectively. With the exclusion of Test Runs 5 and 9, the manure mantle was dry, hard packed and smooth prior to the rainfall event. Tests Runs 1, 2, 3, 4 and 5 were conducted at a Sterling, Colorado, feedlot and Runs 6, 7, 8 and 9 were conducted at a feedlot in the Fort Collins, Colorado, area.

Time to Runoff (TRF)

The time to runoff decreases with an increase in rainfall intensity, surface slope and the initial moisture content of the manure mantle, according to statistical regression analysis (Equation 2, Appendix B). The more the rainfall rate exceeds the intake rate of the manure mantle the faster water will accumulate on the surface. When the surface storage is filled, runoff begins. As the surface slope is increased, there is a corresponding increase in the gravitational force component which is pulling the water down the feedlot surface. A high initial moisture content is indicative of decreased storage capacity and is accompanied by a slower water intake rate.

Accumulated Rainfall to Runoff (ARRF)

The amount of rainfall which is accumulated before runoff begins is an indication of the surface storage available. Empirically, surface storage is known to be dependent upon the surface slope (for a smooth surface), initial moisture content, water intake rate and the capacity for puddling on the feedpen surface. Of the data collected, the initial moisture content had the highest correlation with the accumulated rainfall to runoff of any of the independent variables.

Accumulated Runoff (ARF)

The quantity of runoff expected from a feedlot increases with respect to the total rainfall applied and the runoff rate (see Equation 3, Appendix B). The amount of water which runs off a surface is naturally dependent upon the amount of water supplied for runoff. This supply is derived from two sources:

1. The total quantity applied, and
2. The degree to which the application rate (it has been determined above, the runoff rate is dependent upon the rainfall intensity) exceeds the intake rate of the surface.

This second phenomenon is also reflected in the time to runoff and the accumulated rainfall to runoff.

Other researchers[77,78,79] have developed equations relating the expected runoff only with the depth of rain applied. Kreis et al.[80] developed the equation for unsurfaced feedlots:

$$RU = 0.500\ RA - 0.124$$

where: RU = runoff
RA = rainfall

The Soil Conservation Service has suggested an equation for determining the volume of runoff from a feedlot surface. This equation is:

$$Q = \frac{(P - 0.352)^2}{P + 1.41}$$

where: Q = runoff
P = precipitation

In Figure 10 these two curves and a third one, resulting from data collected in these tests, are plotted. The data points obtained from six of the test runs conducted are also indicated, for reference. The third equation plotted is:

$$ARF = 0.33\ TR - 0.20$$

where: ARF = runoff

TR = total rainfall

From Figure 10 the Soil Conservation Service equation gave the highest estimate of the runoff quantity with all data points lying on or below the Soil Conservation Service prediction.

Settleable Solids (SSLDS)

The settleable solids content appears to be primarily a function of the initial moisture content of the manure mantle and the depth of the manure mantle. As noted above in the background information, thick manure packs usually have a higher moisture content than do the thinner packs, and high moisture content manure holds high concentrations of dissolved organic matter at the onset of rainfall. Therefore, it would seem the moisture content of the manure mantle is the determining factor in regard to the settleable solids content of the feedlot runoff. The initial moisture content had the highest correlation of the independent variables.

Volatile Solids (VSLDS)

The volatile solids content shows high correlation with the surface type of the feedlot and/or the depth of manure mantle. Due to the testing scheme these two variables cannot be necessarily separated. The effects ration, surface type, depth of manure mantle and runoff rate have on the volatile solids is reflected in Equation 5 of Appendix B. According to stepwise regression analysis, surface type and runoff rate had dominant effects, with the ration showing only a slight effect on the volatile solids content. The depth of the manure mantle did not enter the regression equation but did have an appreciable correlation with volatile solids. It is logical to expect the volatile solids to increase with high concentrate rations, because concentrates have more nutrients and less minerals than do the roughages. Faster

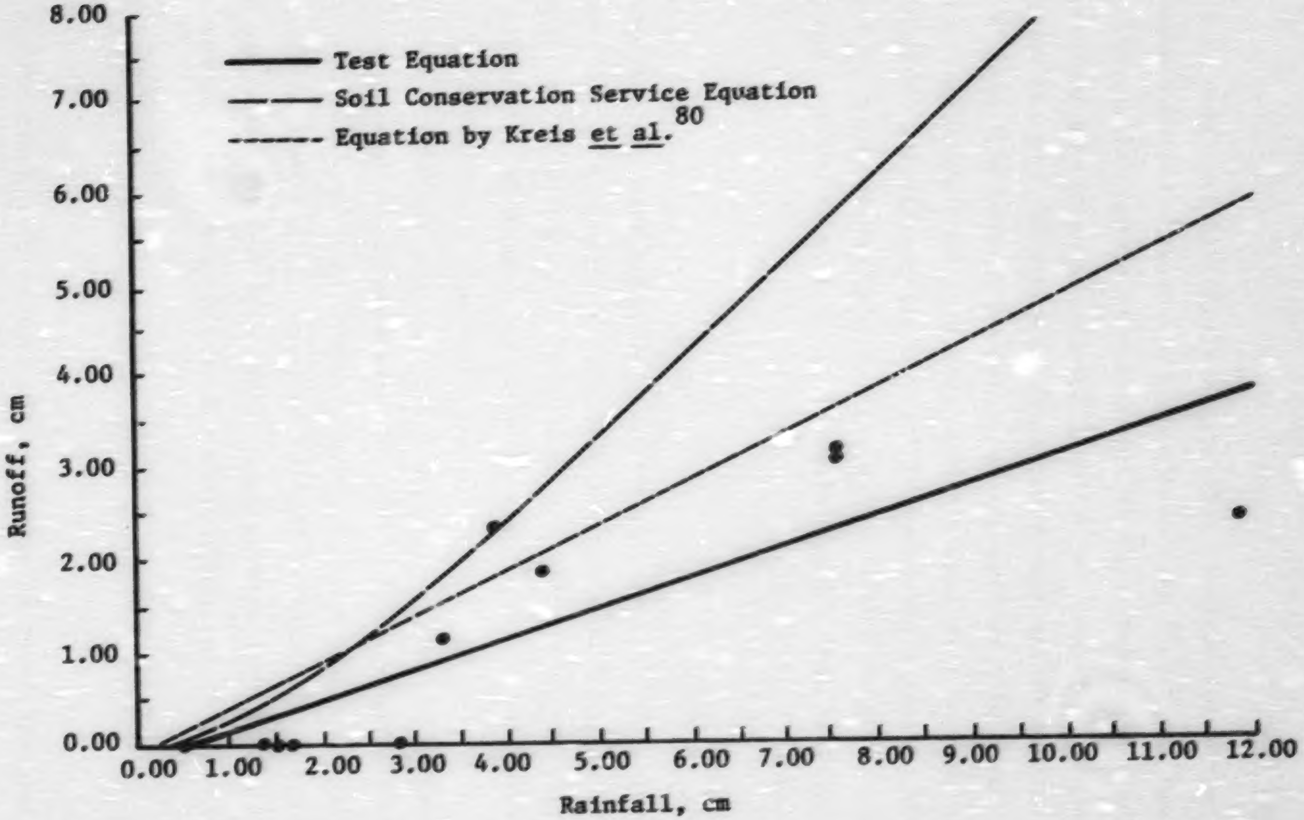

Figure 10. Rainfall-runoff relationships for beef cattle feedlots

runoff rates do not provide time for the organic matter to be dissolved and transported; therefore, the volatile solids content is lower in high velocity runoff.

Inorganic Solids (ASH)

Stepwise regression analysis indicates increases in the depth of the manure mantle and the runoff rate decreases the inorganic solids content of the runoff. The ash content tends to increase with higher initial moisture contents of the manure pack. The depth of the manure mantle is indicated as being the predominant factor (see Equation 6, Appendix B). If the manure pack is thick, there will be less mixing of the underlying soil with the manure. In the case of thin manure packs, dirt will be mixed with the manure, introducing more silicates and minerals into the manure mantle. Initial moisture content and runoff rate coming into the regression equation are reflective of the time available to dissolve the solids and carry them off the feedlot surface.

Total Alkalinity (ALKLN)

Methyl orange, with a color change at pH 4.6, was used to determine the total alkalinity of the runoff samples collected. Increases in the depth of the manure mantle and the runoff rate were inversely related to the alkalinity for the tests conducted. A high initial moisture content of the manure pack increases the alkalinity of the runoff (see Equation 7, Appendix B). A thick manure pack provides the possibility of salts leaching downward. A high moisture content will dissolve more of the salts present in the manure pack. Fast runoff rates limit the time the water and salts are in contact, thus restricting time for the salts to be dissolved and carried away in the runoff water. Also, if the runoff rate is high, there will be more water present (see above discussion on runoff rate) to dilute the runoff to a pH nearer neutral.

pH

The data indicate lower pH values on the pens which had the higher concentrate rations fed in them. This is indicative of the acids present in the concentrate feeds and those acids produced by the biological breakdown of the high protein manure. pH also increases with depth of the manure mantle. Again, deeper manure packs have higher moisture contents and, therefore, higher dissolved salt concentration.

Biochemical Oxygen Demand (BOD)

The BOD on the pens where a high concentrate ration was fed was five times greater, on the average, than those values obtained from the low concentrate, high roughage ration pens. Ration had the highest correlation with BOD followed closely by the depth of manure mantle and the initial moisture content. Increases in the latter two resulted in lower BOD.

Chemical Oxygen Demand (COD)

From information collected, concrete surfaces produce high COD loads coming off a feedlot. Slow runoff rates also produce high COD loads. Faster runoff rates carry low concentrations of dissolved solids (see discussions on volatile and inorganic solids), resulting in lower oxygen demands per unit volume of runoff. Stepwise regression analysis (see Equation 8, Appendix B) indicates ration to have a limited effect on the COD.

It may be noted from Table 21 that all tests conducted on the concrete and dirt surfaces had approximately the same initial conditions. The differences were with regard to the depths of manure mantles on the feedpen floors and the rations being fed to the cattle in these pens. Since the respective depths of the manure mantles are those which would normally be expected for clean concrete or dirt feedlot surfaces, the pollution characteristics may be compared on a clean-pen basis. Rations fed to the beef cattle are varied throughout the growing period of the animals, starting with a high roughage, low concentrate ration and gradually changing to a low roughage, high concentrate ration.

Referring to Table 21 for comparison information, the storage capacities of the two surface types are reflected in the data obtained for time to runoff, accumulated rainfall to runoff, runoff rate and resulting runoff. The lower values for time to runoff and accumulated rainfall to runoff for the concrete versus dirt surfaces indicate less initial surface storage for the concrete surfaces. The high runoff rate and resulting runoff values indicate this trend to continue throughout a rainfall event.

Table 21. SURFACE COMPARISONS USING AVERAGES OF COLLECTED DATA

	Concrete	Dirt
Rainfall intensity, cm/hr	2.3	2.6
Surface slope, %	1.4	1.7
Manure mantle depth, cm	1.6	3.8
Initial moisture content, %	22.4	25.9
Ration, concentrate:roughage	3.80	1.50
Time to runoff, hour	1.25	1.96
Accumulated rainfall to runoff, cm	1.2	1.5
Runoff rate, cm/hr	1.4[a]	1.0[a]
Accumulated runoff, cm	2.0[a]	2.2[a]
Resulting runoff, %	45[a]	30[a]
Settleable solids, ml/l	3.70	1.81
Volatile solids, mg/l	3.80	1.06
Inorganic solids, mg/l	5.67	2.56
Alkalinity, mg/l$CaCO_3$	851	452
pH	7.37	8.07
BOD, mg/l	1020	434
COD, mg/l	6186	1301

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[a] Only Test Runs 1, 3, 4, 6, 7 and 9 were cited.

The runoff quality data indicate the runoff from concrete surfaced feedpens to have higher concentrations of pollutants than does the dirt feedpen runoff. This higher pollution potential of concrete versus dirt feedlots is even more serious when considering 1.5 times more runoff may occur from the concrete surfaces than from the dirt feedlot surfaces. However, considering up to four times as many beef cattle may be confined on a concrete surface as compared to dirt surfaces (Table 17), concrete surfaced feedlots may provide fewer pollutants than dirt feedlots.

CONCLUSIONS

Surfaced feedlot pens have less storage capacity for accumulated rainfall than do unsurfaced pens. Therefore, initial runoff will begin sooner and a large percentage of the precipitation will run off the surfaced areas. Since surfaced areas are generally cleaned more frequently, the storage capacity for rainfall is further reduced. Volatile solids, inorganic solids, alkalinity and COD are all affected by runoff rate.

The concentration of pollutants is generally higher in the runoff from surfaced pen areas than from the unsurfaced pen areas. Suspended materials, especially, are more prone to wash off the surfaced areas and be carried along by the higher velocities found on the surfaced areas. Dissolved organic materials are generally lower from the surfaced areas, since initial runoff is sooner and less time is provided for dissolving material in the runoff.

Rations have a significant effect on the pollution potential of the runoff. Runoff from pens being fed high concentrate rations will have higher concentrations of volatile solids and a higher COD load.

While surfaced feedlot pen areas will have more runoff with more concentrated pollution potential than do unsurfaced pens, the difference can be offset on a per animal basis by increased animal densities.

Runoff collection and treatment facilities for surfaced feedlot areas will require capacities to handle more volume and higher pollution concentrations than unsurfaced areas. Frequent cleaning will increase both requirements.

The Soil Conservation Service prediction equation can be relied upon to give an adequate working estimate of the quantity of runoff which will accrue from a rainfall event.

RECOMMENDATIONS

The runoff collection and treatment facilities for surfaced feedlot areas should provide for handling higher volumes with more concentrated pollution than is required for unsurfaced feedlot pen areas. The difference increases with steeper slopes and more frequent cleaning.

To reduce the runoff volume on a per animal basis, the density of animals on surfaced pens should be increased to utilize the advantages provided by the surfacing and more frequent cleaning.

In this study, the ratio of concentrates to roughage in the ration was a major factor in the pollution concentration of the runoff. Therefore, high concentrate rations fed in frequently cleaned, surfaced pens, should be recognized as a possible source of high pollution potential.

This study indicated rations have more influence on the pollution concentration of the runoff than previous investigators have reported. Additional study is needed, emphasizing the role rations have on the quality of the runoff from both surfaced and unsurfaced feedlot pens.

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SECTION IX

GLOSSARY

All definitions are taken from the 1974 Agricultural Engineers Yearbook[81].

Alkalinity -- The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per litre of equivalent calcium carbonate.

Biochemical oxygen demand (BOD) -- The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. A standard test used in assessing wastewater strength.

Chemical oxygen demand (COD) -- A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

Contamination -- Any introduction into water (air or soil) of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the water (air or soil) unfit for its intended use.

Infiltration rate -- (1) The rate at which water enters the soil or other porous material under a given condition. (2) The rate at which infiltration takes place, expressed as depth of water per unit time, usually in inches or cm per hour.

Leaching -- (1) The removal of soluble constituents from soils or other material by water. (2) The removal of salts and alkali from soils by abundant irrigation combined with drainage. (3) The disposal of a liquid through a nonwatertight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil.

Manure -- The fecal and urinary defecations of livestock and poultry. Manure may often contain some spilled feed, bedding or litter.

Organic matter -- Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structures, comprising compounds consisting of hydrocarbons and their derivatives.

pH -- The reciprocal to the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen-ions, in grams, per litre of solution. Neutral water, for example, has a pH value of 7 and a hydrogen-ion concentration of 10^{-7}.

Percolation rate -- The rate of movement of water under hydrostatic pressure through the interstices of the rock or soil, except movement through large openings such as caves.

Permeability -- The property of a material which permits appreciable movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

Pollution -- The presence in a body of water (or soil or air) of material in such quantities that it impairs the water's usefulness or renders it offensive to the senses of sight, taste, or smell. Contamination may accompany pollution. In general, a public-health hazard is created, but, in some instances, only economy of aesthetics are involved as when waste salt brines contaminate surface waters or when foul odors pollute the air.

Sediment -- (1) Any material carried in suspension by water which will ultimately settle to the bottom after the water loses velocity. (2) Fine waterborne matter deposited or accumulated in beds.

Settleable solids -- (1) That matter in wastewater which will not stay in suspension during a preselected settling period, such as one hour, but either settles to the bottom or floats to the top. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in one hour.

Solids content -- The residue remaining when the water is evaporated away from a sample of water, sewage, other liquids, or semi-solid masses of material and the residue is then dried at a specified temperature, usually 103°C.

Volatile solids -- The quantity of solids in water, wastewater, or other liquids lost in ignition of the dry solids at 600°C.

REFERENCES

81. Agricultural Engineers Yearbook. 1974. Uniform Terminology for Rural Waste Management. p. 462-464.

SECTION X

APPENDICES

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APPENDIX A

SUMMARY OF FIELD DATA ON EFFECT OF ENVIRONMENT ON MANURE QUALITY

KJELDAHL N	TCA N	NH-3	NPN	HEMI-CELL	CELL	LIGNIN	ADF ASH	PH	ASH	DRY MATTER	CRUDE PROTEIN	CRUDE FIBER	MEAN TEMP	DAY	PEN/ LOCATION
2.92	1.56	.43	1.28	9.14	28.38	-0.00	-0.00	6.57	26.97	79.02	1.77	8.27	75.60	312.	181
3.17	1.60	.55	1.57	11.47	26.67	-0.00	-0.00	7.18	25.86	75.70	1.77	8.27	73.60	298.	181
2.46	1.66	.43	1.30	9.01	30.94	-0.00	-0.00	6.26	30.61	45.86	1.77	8.27	77.40	283.	181
2.98	1.54	.33	1.24	6.97	31.64	-0.00	-0.00	6.01	31.10	77.40	1.77	8.27	66.50	268.	181
2.74	1.44	.33	1.09	10.96	29.82	-0.00	-0.00	6.52	25.50	78.49	1.77	8.27	61.30	254.	181
2.08	1.34	.27	.76	8.51	37.16	-0.00	-0.00	6.10	32.19	26.70	1.77	8.27	58.50	241.	181
2.26	1.59	.37	1.26	6.09	34.50	-0.00	-0.00	6.49	30.39	62.60	1.77	8.27	55.60	228.	181
2.80	1.60	.32	1.20	6.15	10.67	5.16	18.47	7.08	30.00	66.60	1.77	8.27	52.50	213.	181
2.56	1.63	.54	1.26	6.60	9.46	5.76	16.50	5.90	32.42	29.60	2.06	19.29	35.40	195.	181
3.19	1.94	.43	1.24	9.90	8.07	8.00	11.03	7.82	24.60	68.00	1.74	6.48	30.80	176.	181
3.21	1.94	.56	1.25	9.36	10.75	1.50	8.35	7.40	21.66	41.50	1.74	6.48	37.90	162.	181
2.97	1.65	.46	1.11	8.20	9.87	2.40	11.63	8.00	22.50	54.70	1.74	6.48	28.60	148.	181
2.76	1.52	.45	.96	6.80	8.50	7.20	11.10	7.05	25.40	34.50	1.74	6.48	19.40	134.	181
2.70	1.66	.63	1.61	3.60	7.94	7.40	14.82	6.63	26.80	33.80	1.74	6.48	19.40	134.	181
2.30	1.47	.36	.91	8.90	7.42	8.30	17.48	6.20	30.80	33.70	1.77	8.27	33.00	120.	181
2.27	1.56	.35	.75	4.40	13.42	4.43	14.98	8.22	32.50	31.60	1.77	8.27	24.10	106.	181
2.03	1.24	.28	.65	6.70	8.94	5.30	22.52	8.60	33.40	29.00	1.76	16.44	21.50	93.	181
2.11	1.27	.25	.86	5.65	12.15	6.40	24.05	7.30	40.20	31.00	2.06	19.29	33.70	44.	181
2.69	1.35	.31	1.14	8.01	37.67	-0.00	-0.00	6.43	39.41	83.20	1.77	8.27	75.60	312.	182
2.22	1.11	.27	1.11	6.43	45.05	-0.00	-0.00	6.50	46.86	85.31	1.77	8.27	73.60	298.	182
2.12	1.43	.21	.91	8.66	38.16	-0.00	-0.00	6.46	38.15	56.97	1.77	8.27	77.40	283.	182
2.31	1.03	.15	1.18	5.22	43.78	-0.00	-0.00	6.04	47.65	73.01	1.77	8.27	66.50	268.	182
2.20	1.55	.25	.65	4.75	37.65	-0.00	-0.00	6.20	33.85	81.76	1.77	8.27	61.30	254.	182
2.91	1.32	.25	.64	8.26	40.12	-0.00	-0.00	6.15	42.05	37.10	1.77	8.27	58.50	241.	182
2.33	1.13	.34	1.26	7.86	39.90	-0.00	-0.00	6.38	44.97	69.20	1.77	8.27	55.60	228.	182
2.36	1.45	.34	.91	4.95	6.21	6.24	25.11	6.30	42.35	91.30	1.77	8.27	52.50	213.	182
2.18	1.38	.35	.70	4.50	36.18	.62	21.42	5.95	47.04	39.40	2.06	19.29	35.40	195.	182
1.35	1.21	.33	.65	6.78	7.10	3.60	12.20	7.56	56.20	66.00	1.74	6.48	30.80	176.	182
2.26	1.44	.43	.82	10.15	10.07	1.20	20.73	7.53	40.00	57.00	1.74	6.48	37.90	162.	182
2.36	1.32	.42	1.08	5.20	11.05	2.50	24.95	7.68	37.80	48.40	1.74	6.48	28.60	148.	182
1.85	1.25	.26	.60	5.20	4.85	7.80	27.95	7.43	40.80	58.40	1.74	6.48	19.40	134.	182
1.61	1.06	.25	.57	5.80	4.83	6.40	38.77	7.27	50.90	54.60	1.77	8.27	33.00	120.	182

%KJELDAHL N	TCA N	PEPSN N	NPN	HEMI-CELL	CELL	LIGNIN	ADF ASH	PH	ASH	DRY MATTER	CRUDE PROTEIN	CRUDE FIBER	MEAN TEMP	DAY	DEPT/ LOCATION
1.65	1.31	.16	.36	11.70	17.86	4.80	17.64	7.37	39.80	31.10	1.77	8.27	26.10	168.	182
1.96	1.33	.15	.41	5.10	9.76	6.70	28.36	8.38	38.00	53.20	1.76	16.44	21.50	93.	182
2.66	1.38	.35	1.29	10.69	36.91	-0.00	-0.00	6.55	39.49	78.21	1.77	8.27	75.60	312.	183
2.18	1.15	.25	.99	6.22	41.34	-0.00	-0.00	6.22	39.50	79.36	1.77	8.27	73.60	298.	183
2.41	1.51	.35	.90	3.93	41.47	-0.00	-0.00	6.60	39.41	47.68	1.77	8.27	77.40	293.	183
2.27	1.33	.26	.96	5.37	61.43	-0.00	-0.00	6.48	44.11	71.73	1.77	8.27	66.50	268.	183
2.20	1.42	.24	.86	3.39	39.14	-0.00	-0.00	6.35	40.90	83.85	1.77	8.27	61.30	256.	183
2.10	1.36	.24	.75	6.66	43.85	-0.00	-0.00	6.10	40.70	32.70	1.77	8.27	58.50	241.	183
2.51	1.45	.36	1.03	7.26	37.77	-0.00	-0.00	5.57	36.96	45.30	1.77	8.27	55.60	228.	183
2.06	1.28	.28	.78	4.37	10.26	3.56	29.35	6.75	43.53	80.60	1.77	8.27	52.50	213.	183
1.72	1.17	.26	.55	2.60	4.05	9.66	32.59	6.13	57.12	30.60	2.06	19.29	35.60	199.	183
2.51	1.76	.46	.75	5.60	10.38	4.40	17.22	7.31	36.00	66.30	1.76	6.48	39.80	176.	183
2.42	1.51	.45	.91	4.52	8.20	1.60	27.10	7.73	41.20	52.50	1.76	6.48	37.00	162.	183
2.43	1.66	.46	.78	.70	11.50	2.10	22.00	7.54	32.40	53.03	1.74	6.48	28.60	148.	183
2.11	1.31	.25	.40	4.39	5.26	7.40	26.56	7.51	39.70	51.60	1.74	6.48	19.60	134.	183
2.09	1.42	.30	.67	9.00	6.03	8.80	22.97	6.47	36.20	40.40	1.77	8.27	33.00	120.	183
1.86	1.23	.31	.66	10.00	11.91	3.90	26.39	8.11	41.60	38.60	1.77	8.27	26.10	106.	183
1.66	1.22	.15	.44	10.49	11.85	8.20	23.45	8.12	38.20	33.80	1.76	16.44	21.50	93.	183
3.05	1.84	.35	1.17	10.90	25.02	-0.00	-0.00	6.10	18.22	65.76	1.71	12.56	75.60	312.	171
2.55	1.56	.25	.89	9.96	27.42	-0.00	-0.00	7.11	18.28	75.39	1.71	12.56	73.60	298.	171
3.11	1.90	.36	1.22	10.75	25.18	-0.00	-0.00	6.60	22.59	75.46	1.77	8.27	66.50	268.	171
3.05	1.82	.44	1.27	6.57	29.58	-0.00	-0.00	5.44	22.40	75.16	1.77	8.27	61.10	256.	171
2.49	1.36	.62	1.66	7.20	32.28	-0.00	-0.00	5.96	25.88	30.40	1.77	8.27	58.50	241.	171
3.10	1.63	.65	1.47	10.58	26.71	-0.00	-0.00	5.50	24.83	47.00	1.77	8.27	55.60	228.	171
2.60	1.72	.43	.87	8.26	9.33	3.50	17.42	6.86	29.23	70.60	1.76	6.48	52.50	213.	171
2.75	1.43	.45	1.26	3.60	10.56	6.44	21.06	5.90	41.72	31.40	1.77	8.27	35.40	199.	171
2.43	1.63	.46	1.01	14.74	12.26	5.20	12.96	7.46	30.40	60.80	1.76	16.44	39.80	176.	171
2.42	1.43	.54	.99	2.90	14.02	3.10	14.58	7.91	32.50	62.50	1.74	6.48	28.60	148.	171
3.47	2.14	.55	1.32	6.80	8.48	5.00	8.92	7.11	19.30	44.20	1.74	6.48	19.40	134.	171
3.23	1.59	.64	1.33	10.20	6.90	6.00	8.50	6.73	20.40	49.60	1.74	6.48	33.00	120.	171
3.15	1.71	.76	1.45	7.60	10.43	2.30	8.57	7.90	21.00	51.00	1.74	6.48	26.10	106.	171
2.40	1.52	.43	1.28	10.80	5.36	4.40	8.66	7.71	19.00	46.10	1.76	6.48	21.50	93.	171
3.86	1.65	.51	1.35	11.00	9.01	3.40	11.89	7.42	22.70	43.00	1.74	6.48	33.70	86.	171

*KJELDAHL %	TCP %	NP-N %	NPN	HEMI-CELL	CELL	LIGNIN	ADF ASH	PH	ASH	DRY MATTER	CRUDE PROTEIN	CRUDE FIBER	MEAN TEMP	DAY	PENS LOCATION
3.26	1.04	.42	1.40	12.08	26.13	-0.00	-0.00	6.66	26.13	86.51	1.71	12.56	75.60	312.	172
2.72	2.67	.15	.65	11.91	29.27	-0.00	-0.00	6.67	18.07	92.35	1.71	12.56	73.60	298.	172
1.86	1.76	.36	1.27	13.26	25.53	-0.00	-0.00	6.14	24.17	78.62	1.77	8.27	66.50	268.	172
2.06	1.78	.33	1.16	17.73	26.93	-0.00	-0.00	6.32	26.18	90.95	1.77	8.27	61.30	254.	172
2.30	1.53	.36	.87	9.04	18.56	-0.00	-0.00	6.21	31.93	38.50	1.77	8.27	58.50	241.	172
2.68	1.51	.36	1.17	7.87	35.11	-0.00	-0.00	6.60	33.38	84.10	1.77	8.27	55.60	228.	172
2.53	1.28	.25	1.26	8.66	4.93	5.50	27.14	6.72	39.07	90.50	1.74	6.48	52.50	213.	172
3.15	1.43	.54	1.33	5.10	19.76	5.76	11.60	5.81	29.26	26.20	1.76	16.46	39.40	149.	172
2.15	1.37	.17	.74	6.00	-32.60	7.10	22.57	7.10	42.30	86.90	1.74	6.48	28.60	178.	172
2.20	1.67	.55	1.21	10.00	0.99	1.90	15.81	7.06	32.60	63.90	1.76	6.48	19.60	168.	172
3.56	2.66	.72	1.66	9.00	7.31	7.40	6.89	8.20	19.60	57.50	1.76	6.49	33.00	134.	172
3.18	1.93	.49	1.21	10.50	10.63	4.70	6.67	7.06	20.80	63.30	1.74	6.48	24.10	120.	172
3.22	1.64	.66	1.37	11.00	10.85	3.00	6.95	8.13	18.20	42.00	1.74	6.48	21.50	108.	172
3.17	1.66	.76	1.51	13.00	7.72	4.40	6.68	8.01	28.40	47.80	1.74	6.48	21.50	93.	172
2.64	1.86	.50	1.11	10.68	9.66	4.20	11.16	8.11	23.80	53.20	1.74	6.48	31.70	46.	172
2.49	1.72	.35	.97	10.97	33.15	-0.00	-0.00	6.02	32.52	76.18	1.71	12.56	75.60	312.	173
2.79	1.55	.13	.75	13.85	30.10	-0.00	-0.00	6.72	22.29	90.08	1.71	12.56	73.60	298.	173
2.55	1.48	.33	1.11	9.44	37.30	-0.00	-0.00	6.05	39.02	72.05	1.77	8.27	66.50	268.	173
2.41	1.45	.41	1.13	8.12	33.63	-0.00	-0.00	6.18	16.22	63.88	1.77	8.27	61.30	254.	173
1.83	1.05	.26	.75	12.09	50.77	-0.00	-0.00	6.13	46.12	41.10	1.77	8.27	58.50	241.	173
2.30	1.27	.35	1.11	7.62	35.57	-0.00	-0.00	6.16	60.97	67.10	1.77	8.27	55.60	228.	173
2.36	1.35	.31	.95	6.20	8.11	6.36	30.66	6.50	66.30	79.90	1.76	6.48	52.50	213.	173
1.86	1.26	.33	.62	.50	9.80	7.62	32.38	5.93	50.32	37.50	1.77	8.27	35.60	149.	173
2.16	1.31	.17	.85	5.80	16.52	2.70	26.78	7.52	45.20	77.20	1.76	16.46	39.80	178.	173
1.59	1.1-	.41	.80	5.10	10.61	1.70	36.00	7.61	41.20	71.20	1.74	6.48	28.60	168.	173
2.60	1.55	.36	.86	2.60	6.20	7.60	23.60	6.91	37.80	51.20	1.74	6.48	13.60	134.	173
2.87	1.66	.56	1.22	9.00	8.21	6.70	13.89	6.56	27.60	56.20	1.74	6.48	33.30	120.	173
2.36	1.37	.51	1.03	9.60	3.12	2.20	27.08	7.68	40.30	51.90	1.74	6.48	26.10	108.	173
2.01	1.26	.27	.77	2.60	8.65	3.50	32.15	7.22	46.70	55.80	1.74	6.48	33.70	46.	173
2.76	1.61	.73	1.32	12.20	5.21	4.20	17.09	8.12	24.60	51.20	1.74	6.48	21.50	93.	173
2.26	1.86	.14	.42	11.53	36.93	-0.00	-0.00	7.68	35.52	91.58	1.77	8.27	75.60	312.	551
2.19	1.60	.14	.51	9.59	40.98	-0.00	-0.00	7.85	38.98	89.55	1.77	8.27	73.60	298.	551
2.26	1.66	.16	.80	2.78	48.33	-0.00	-0.00	7.18	43.81	64.22	1.77	8.27	77.60	243.	551

KJELDAHL N	TCA N	NH-N 3	NPN	HEMI-CELL	CELL	LIGNIN	ADF ASH	PH	ASH	DRY MATTER	CRUDE PROTEIN	CRUDE FIBER	MEAN TEMP	DAY	PEN/ LOCATION
2.85	1.84	.06	.40	7.23	43.06	-0.00	-0.00	7.45	34.52	79.43	1.77	8.27	66.50	268.	551
2.23	1.76	.05	.45	9.75	43.25	-0.00	-0.00	7.00	35.18	62.59	1.77	8.27	61.30	254.	551
1.72	1.66	.04	.06	11.13	48.02	-0.00	-0.00	7.84	40.85	24.30	1.77	8.27	58.50	241.	551
1.92	1.57	.11	.34	7.67	12.13	5.45	26.72	8.62	36.08	63.10	2.09	27.01	52.50	213.	551
1.80	1.22	.07	.58	3.90	13.17	8.66	28.77	7.49	49.99	35.40	2.09	27.01	35.40	195.	551
2.14	1.76	.05	.39	7.48	19.90	4.80	18.90	8.68	30.48	48.30	2.09	27.01	30.80	176.	551
2.10	1.56	.06	.52	11.28	20.29	5.00	16.21	8.14	25.90	32.40	2.09	27.01	37.90	162.	551
2.15	1.35	.21	.89	3.57	17.20	2.70	27.90	7.57	41.80	57.50	2.09	27.01	28.60	148.	551
2.54	1.56	.31	1.06	4.40	5.90	7.90	26.20	6.77	33.10	37.20	2.06	19.29	19.40	134.	551
2.13	1.25	.25	.45	4.60	8.31	6.60	25.09	6.32	38.30	39.70	1.77	8.27	33.00	120.	551
2.28	1.33	.46	.96	4.08	8.40	3.40	24.20	7.72	42.90	39.00	2.06	19.29	24.10	106.	551
2.37	1.44	.36	.93	6.30	9.01	2.40	25.39	7.01	37.08	45.60	1.74	6.48	33.70	84.	551
2.13	1.77	.37	.36	10.66	34.75	-0.00	-0.00	7.52	35.45	92.96	1.77	8.27	75.60	312.	552
1.72	1.35	.05	.37	10.32	47.01	-0.00	-0.00	7.71	47.45	90.56	1.77	8.27	73.60	298.	552
1.60	1.21	.04	.19	5.15	55.78	-0.00	-0.00	7.50	56.95	51.65	1.77	8.27	77.40	283.	552
1.63	1.46	.04	.14	4.00	50.38	-0.00	-0.00	7.45	49.23	91.73	1.77	8.27	66.50	268.	552
1.44	1.23	.04	.21	8.79	54.56	-0.00	-0.00	8.05	53.41	102.56	1.77	8.27	61.30	254.	552
1.57	1.46	.03	.10	12.19	52.25	-0.00	-0.00	7.43	44.25	32.20	1.77	8.27	58.50	241.	552
1.07	1.03	.04	.06	3.93	8.38	5.26	46.75	8.50	62.47	90.50	2.09	27.01	52.50	213.	552
1.41	1.37	.04	.24	8.70	16.86	8.32	26.62	7.11	46.03	30.40	2.09	27.01	35.40	195.	552
1.79	1.34	.04	.45	7.00	12.46	7.20	27.44	7.94	14.90	87.20	2.09	27.01	34.80	176.	552
2.12	1.51	.16	.55	7.90	16.55	4.40	23.65	8.93	30.99	55.20	2.09	27.01	37.50	162.	552
1.41	.95	.22	.66	1.66	14.45	5.26	17.15	7.20	56.20	56.20	2.09	27.01	28.60	148.	552
2.23	1.57	.24	.66	5.70	7.70	7.70	22.48	6.90	34.20	43.70	2.06	19.29	19.40	134.	552
2.22	1.45	.25	.60	6.60	8.86	7.20	22.96	6.32	34.50	45.30	1.77	8.27	33.00	120.	552
1.83	1.43	.05	.48	6.00	8.17	6.00	31.63	7.72	41.00	33.60	2.06	19.29	24.10	106.	552
2.42	1.65	.33	.93	9.40	10.14	3.00	15.42	7.65	30.60	47.20	1.74	6.48	33.70	84.	552
1.47	1.34	.05	.13	13.24	48.00	-0.00	-0.00	7.50	50.84	96.14	1.77	8.27	75.60	312.	553
.76	.53	.06	.06	.47	63.37	-0.00	-0.00	8.40	74.42	40.83	1.77	8.27	73.60	298.	553
.54	.46	.03	.10	-.91	71.69	-0.00	-0.00	7.10	82.06	88.84	1.77	8.27	77.40	283.	553
.80	.43	.04	.17	.62	68.60	-0.00	-0.00	8.30	74.24	87.20	1.77	8.27	66.50	268.	553
.61	.47	.03	.13	4.61	68.68	-0.00	-0.00	7.69	79.12	65.89	1.77	8.27	61.30	254.	553
1.27	.95	.08	.32	4.59	1.89	5.72	45.12	8.07	59.44	91.00	2.09	27.01	52.50	213.	553

KJELDAHL N	TCA N	NH-N %	NPN	HEMI-CELL	CELL	LIGNIN	ADF ASH	PH	ASH	DRY MATTER	CRUDE PROTEIN	CRUDE FIBER	MEAN TEMP	DAY	PEN/ LOCATION
2.13	1.64	.05	.47	12.10	17.75	10.86	13.89	7.56	13.47	25.90	2.09	27.01	35.40	145.	553
1.79	1.45	.06	.31	10.50	39.40	4.40	16.76	9.02	36.30	85.10	2.09	27.01	39.80	176.	553
1.86	1.46	.05	.40	5.71	14.24	4.50	22.42	7.74	32.70	51.30	2.09	27.01	37.40	162.	553
1.70	1.04	.26	.73	-2.74	12.25	3.30	30.15	6.05	51.60	59.20	2.09	27.01	28.60	148.	553
2.33	1.57	.23	.60	7.28	6.74	8.00	23.61	6.42	35.20	47.20	2.06	19.29	19.40	134.	553
2.21	1.46	.26	.76	6.20	10.51	6.90	19.09	6.42	31.80	44.00	1.77	8.27	33.00	120.	553
1.81	1.55	.06	.22	9.20	17.30	5.60	22.50	7.92	39.00	72.30	2.06	19.29	24.10	106.	553
2.22	1.46	.30	.74	6.80	12.65	3.50	20.65	7.98	41.20	45.20	1.74	6.48	33.70	84.	553

APPENDIX B

SUMMARY OF MULTIPLE LINEAR REGRESSION EQUATIONS OBTAINED

Equation 1:

$\mathrm{RFR} = 0.10 + 0.38\ \mathrm{ARI}$ $R^2 = 0.54$

Equation 2:

$\mathrm{TRF} = 4.79 - 1.51\ \mathrm{ARI} - 1.09\ \mathrm{SS} - 0.01\ \mathrm{BMC}$ $R^2 = 1.00$

Equation 3:

$\mathrm{ARF} = -0.04 + 0.18\ \mathrm{TR} + 0.98\ \mathrm{RFR}$ $R^2 = 0.80$

Equation 4:

$\mathrm{ARF} = 0.76 + 0.22\ \mathrm{TR}$ $R^2 = 0.47$

Equation 5:

$\mathrm{VSLDS} = 5.78 - 2.26\ \mathrm{ST} + 0.32\ \mathrm{R} - 1.78\ \mathrm{RFR}$ $R^2 = 0.74$

Equation 6:

$\mathrm{ASH} = 8.35 - 3.88\ \mathrm{DMM} + 0.03\ \mathrm{BMC} - 1.78\ \mathrm{RFR}$ $R^2 = 0.81$

Equation 7:

$\mathrm{ALKLN} = 1134.13 - 527.98\ \mathrm{DMM} + 8.55\ \mathrm{BMC} - 248.63\ \mathrm{RFR}$ $R^2 = 0.81$

Equation 8:

$\mathrm{COD} = 10{,}218.61 - 4252.01\ \mathrm{ST} + 402.41\ \mathrm{R} - 2563.05\ \mathrm{RFR}$ $R^2 = 0.74$

APPENDIX C

MEAN, MINIMUM AND MAXIMUM VALUES FOR COLLECTED DATA

Variable	Mean	Minimum	Maximum
Time to runoff, hour	1.6	0.2	8.0[a]
Accumulated rainfall to runoff, cm	1.54	0.51	3.35[a]
Resulting runoff, percent	36.	16.	59.
Settleable solids, ml/l	2.71	0.15	17.00
Volatile solids, mg/l	2.20	0.33	6.44
Inorganic solids, mg/l	3.85	0.54	8.61
Alkalinity, mg/l$CaCO_3$	615.	194.	1236.
pH	7.78	7.10	8.70
BOD, mg/l	481.	60.	1720.
COD, mg/l	3326.	494.	1122.

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[a] Extrapolated values for Test Run 8.

APPENDIX D

COMPOSITE DATA SHEET

Sample number	Avg. rainfall intensity, cm/hr	Surface type	Surface slope, %	Manure mantle depth, cm	Initial moisture content, %	Ration, concentrate: roughage	Runoff rate, cm/hr	Total rainfall, cm	Time, hr	Time to runoff, hr	Accumulated rainfall to runoff, cm	Runoff rate, cm/hr	Accumulated runoff, cm	Resulting runoff, %	Settleable solids, ml/l	Volatile solids, mg/l	Inorganic solids, mg/l	Alkalinity, mg/l CaCO$_3$	pH	BOD, mg/l	COD, mg/l	Final moisture content, %
Run 1	4.2	Concrete	1.7	1.8	12.0	5.25		7.6	1.8	0.3	1.3	2.3	3.4	45								59.3
8-19-1							0.1		0.3				0.0		8.60	6.44	8.61	1003	7.15	626	9407	
8-19-2							2.8		1.1				1.6		2.70	3.85	5.16	727	7.50	596	5156	
8-19-3							2.6		1.8				3.4		1.12	1.99	3.65	595	7.50	750	3188	
Run 2	2.2	Dirt	0.8	2.3	7.3	5.25		11.7	5.4	0.3	0.9	2.8	14.2	121								37.0
8-26-1							0.6		0.4				0.1		2.90	2.16	3.88	643	7.40	1148	2130	
8-26-2							1.9		0.9				0.8		1.55	0.69	4.31	349	7.30	840	1584	
8-26-3							3.4		1.9				3.4		1.25	1.36	2.98	517	7.57	628	1036	
8-26-4							2.2		3.9				8.5		1.20	1.41	3.41	568	7.40	880	1504	
8-26-5							2.2		5.4				14.0		1.23[a]	1.70	3.67	821	7.33	1100	2912	
Run 3	1.9	Concrete	2.7	1.3	5.4	3.31		3.9	2.0	0.6	1.3	1.6	2.3	59								65.2
8-27-1							0.4		0.7				0.2		1.10	1.76	3.77	565	7.30	848	2150	
8-27-2							1.4		1.1				0.6		1.95	3.87	5.44	755	7.40	1580[b]	3550	
8-27-3							1.9		2.0				2.3		2.05	3.17	6.79	843	7.18	1720[b]	8870	
Run 4	0.4	Concrete	0.5	1.3	10.9	3.31		2.1	6.0	3.9	1.5	0.2	0.3	16								67.6
9-6-1							0.1		4.4				0.1		1.40	4.76	6.46	988	7.10	--	7324	
9-6-2							0.2		5.6				0.2		2.30	3.85	6.54	1004	7.30	--	7216	
Run 5	2.8	Concrete	0.5	2.0	61.2	3.31		5.8	2.1	0.2	0.6	2.6	3.0	85								67.6
9-7-1							0.0		0.2				0.0		11.10	3.58	6.96	1236	7.45	--	10010	
9-7-2							3.0		0.7				1.1		6.60	2.15	4.53	864	7.55	--	5312	
9-7-3							3.1		2.0				4.6		4.30	1.97	3.62	640	7.62	--	2783	
Run 6	1.9	Dirt	2.5	4.3	22.4	0.25		7.6	4.0	0.7	1.7	1.0	3.1	42								51.7
10-9-1							0.3		0.8				0.1		0.20	0.89	2.85	298	7.90	100	751	
10-9-2							0.9		1.3				0.5		0.95	0.73	2.48	316	8.00	112	544	
10-9-3							1.1		2.3				1.5		0.13	0.86	3.12	324	8.15	148	665	
10-9-4							1.0		4.0				3.1		0.18	0.46	1.33	284	8.30	112	574	
Run 7	3.7	Dirt	1.6	4.3	15.0	0.25		11.9	3.2	0.6	2.8	0.9	2.4	21								64.9
10-12-1							0.4		0.7				0.1		0.40	0.44	0.85	220	8.70	140	1122	
10-12-2							0.9		1.2				0.4		0.65	0.40	0.63	208	8.70	123[c]	1064	
10-12-3							0.5		2.1				1.8		0.15	0.33	0.59	200	8.70	80	785	
10-12-4							1.4		3.0				2.0		0.90	0.34	0.54	194	8.80	60	496	
Run 8	0.4	Dirt	2.0	4.3	26.6	0.25		2.3	6.0	8.0[b]	3.4[b]	0.0	0.0	0								
Run 9	2.8	Dirt	2.0	4.3	38.9	0.25		3.3	1.2	0.2	0.5	1.1	1.1	34								57.2
10-16-1							0.4		0.3				0.0		17.00	2.34	3.21	890	8.42	520	2044	
10-16-2							0.6		0.9				0.6		0.45	1.74	4.61	948	8.40	520	2337	

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[a] Average value.

[b] Extrapolated values.

[c] Weighted average value.